# INDUSTRIAL ENGINEERING

## PART ONE

# INDUSTRIAL ENGINEERING

## A HANDBOOK

OF

USEFUL INFORMATION FOR MANAGERS, ENGINEERS, SUPERINTENDENTS, DESIGNERS, DRAFTSMEN AND OTHERS ENGAGED IN CONSTRUCTIVE WORK

BY

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PART I

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# PREFACE

In the preparation of this handbook the writer attempts a systematic arrangement of a considerable volume of useful information for engineers, much of which has not been readily accessible to the public. The collection includes separate specifications relating to the chemical and physical properties of practically all of the materials entering into engineering work for the U. S. Government. The importance and economic value of the data thus presented will be recognized by manufacturers and engineers engaged in Government work not only, but this value extends into every department in industrial engineering.

The usefulness of this handbook will not rest so much upon the extent of the compilation as upon the practical nature of the data presented; a feature made possible through the free use of working drawings contributed for insertion in these pages. Selections from these drawings appear throughout the entire work in carefully prepared illustrations accompanied in most cases by tables of working dimensions; these cover a wider range of detail than is common in books of this class. It has been the constant aim of the writer that such data shall be so complete that principal dimensions given in any table may, with suitable adaptations, be used directly in the preparation of shop drawings, and without the labor of recalculating.

Correct proportions, in series, cannot be had by selecting an acceptable detail and making one of its dimensions a unit, and then assigning proportional values to the other dimensions, except within very narrow limits. Suppose a series of strap joints as in the table, page 601; diameters ranging from a 3-inch to a 12-inch pin; the writer's method is to complete two designs similar in detail, one for the smallest and the other for the largest diameter of pin, then measuring the proportional differences graphically obtained for intermediate sizes.

There are numerous machine details which are now designed to be complete in themselves, and with very slight changes made to fit into any machine where such a detail is demanded; many examples of this kind are included in this work; in all cases the nature of the design and the properties of materials entering into it are fully considered and the proportions fixed once for all. Pulleys are a familiar example; they are designed for single or double belts, as also double extra heavy for very severe service, but once designed and patterns made, no further changes occur; the pulley becomes one of many units in a plant requiring no further attention on the part of the designer than the mere selection of size and strength.

So-called empiricism, or the reliance on direct observation and experience to the exclusion of theories or assumed principles in machine design, if it ever existed, is no longer in use; many of the so-called empirical or practical rules are in reality founded upon carefully conducted experiments, or the result of long and methodical observation in the working of machines, the ultimate proportions being fixed to safely carry the load regardless of conventional factors of safety; the latter are not believed to be "factors of ignorance" so much as they are generous allowances made to withstand the effect of forces too complex to be dealt with mathematically or physically. Rigidity depends largely upon the form and details of construction. The chemical and physical properties of any material used in engineering is now known with precision. The data relating to strength of materials in this work are wholly those obtained by direct experiment, mainly in testing machines owned and operated by the U. S. Government.

There will be noticed throughout the book a general tendency toward steam-engine details, due in large measure to the writer's long familiarity with that subject. Two satisfactory types of steam-engines are now in use—the modern locomotive engine and

the triple expansion marine engine; both of these use steam pressures, seldom less than 165 pounds per square inch. In locomotive design the present proportions are the outcome of a practical acquaintance with the success or failure of each and every detail, covering experiences in thousands of locomotives with every peculiarity of design, operating on road-beds of every conceivable variety, often under conditions that would seem to invite failure, and through it all the locomotive stands the test with an economic margin that invites confidence and places upon its design and proportions the seal of approval. Similarly the success of the modern triple expansion marine steam-engine, the designs for which are based upon accurate knowledge of the strength and elasticity of materials employed, to which is added an increment in size, based upon experience, to resist stresses occurring at irregular intervals with a suddenness that would seem to imperil the safety of the engine; the proportioning of parts that will completely absorb such shocks without harm and without stoppage in service, is one of the results of thorough technical training supplemented by experiences which can only be had at sea.

There has been no attempt—in fact, the writer disavows any intention of making this a text-book in engineering. The designs illustrated and accompanied by tables of working dimensions are based mainly upon marine and railroad practice, than which no severer working tests occur; the proportions given have long since passed the experimental stage and are known to be ample for the controlling unit, in any given case. Machine design in its narrowest applications is all that is attempted in this work; it has been his opinion throughout that the theory of machines, applied kinematics or machines considered as modifying motion, applied dynamics or machines considered as modifying both motion and force, are subjects requiring special mathematical treatment, and therefore foreign to the present purpose: he contents himself with the simple presentation of some acceptable details in machine construction.

The writer is under obligations to many professional friends contributing and assisting in the selection of material for these pages. His thanks are especially due officials of the Navy Department, the Bureau of Mines, the Bureau of Standards, Examiners in several of the Departments in the U. S. Patent Office; for courtesies in the Library of Congress, the Smithsonian Institution, etc. Extended use has been made of official reports on materials forming the basis of engineering specifications now used in Government contracts, especially those relating to the Navy. Free use has also been made of the Records of Tests made at the Watertown Arsenal, the Washington Navy Yard, and other Governmental Laboratories. In this connection it will be understood that the official reports and specifications appearing in this book are for the information of the reader, and not herein officially published.

As to the apparent exclusion of excellent work done by several Societies in Testing Materials, as well as to results of tests made public by railroads, steel works, forges, foundries, and other industrial plants, it occurs only through lack of space; preference is given the Government Specifications based upon extended chemical and physical investigations because, as presented, they are more or less mandatory in their application.

Free use has been made of valuable contributions to the various engineering societies, magazines, and trade papers covering almost every department of technology. The writer's collection of such material is large, and as most of the papers have been prepared by experts their value is correspondingly great; the collection thus serves to supplement some of the more recent books authoritatively.

With the development of the subjects selected for this book it has become necessary to divide the work into two parts. The present volume, Part I, deals mostly with the chemical and physical properties of the materials used in engineering, particularly such as are called for in Government specifications; these specifications are so numerous and conform so minutely to the official terms, that the space occupied by them is more than double that originally assigned. This has been the case in other sections as well, but the expansion of the work is believed to be wholly in the interest of and will prove doubly useful to, the reader.

Part II is in active preparation for early publication.

The long delay after the preliminary announcement regarding its preparation for early publication has been due to the industrial changes which have taken place through-

out our country because of the European War, an occurrence which has made necessary many changes in the book, including the rearrangement and rewriting of whole sections, the preparation of new drawings, the calculating of new tables, all of which has taken much time, but it has greatly increased the value and importance of the book.

Complete accuracy is not expected in a work involving so much detail as does this, and the writer can only say with respect to this detail that the present work represents an extended and thoroughly earnest effort on his part to secure perfectly reliable material, arranging it in convenient sequence, presenting it in clearly printed pages and carefully indexing the whole for ready reference.

WILLIAM M. BARR.

NEW YORK,
September, 1918.

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In Preparation for Early Publication

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# INDUSTRIAL ENGINEERING

## SECTION I

## UNITS AND STANDARDS

A unit is an acknowledged or standardized quantity in terms of which other quantities may be measured, results recorded, comparisons made, and measurements executed in experimental demonstration. The fundamental units in terms of which every measurement must be executed are those of Time, Space, and Mass.

**Time.**—Standards of time are derived from the revolution of the earth about its axis, which has an inclination of about 23° 28′ from a perpendicular to its plane. The motion of its rotation is from west to east. The Mean Solar Day is the mean interval which elapses between the sun's crossing the meridian, or being situated directly south of a place, and the next occasion on which it crosses that line. Besides rotating on its own axis, the earth describes an ellipse around the sun; the effect of these combined movements is to alter the length of the solar day, a variation occurs throughout the year of from $14\frac{1}{2}$ minutes fast to $16\frac{3}{4}$ minutes slow. A mean solar day is the average or mean of all the solar days in a year; it is divided into 24 hours, each hour into 60 minutes and each minute into 60 seconds; therefore, one second represents $24 \times 60 \times 60 = 86400$ part of a solar day; the usual subdivision of seconds is decimal.

**The Unit of Time** in engineering is one second of mean solar time. For convenience, other and larger units are often used, such as revolutions per minute, miles per hour, and so forth.

**Space** is a necessary representation which serves for the foundation of all external intuitions. It is not a conception which has been derived from outward experiences. We can never imagine the non-existence of space, though we may easily enough think that no objects are found in it. Intuition lies at the root of all our conceptions of space. We can only represent to ourselves one space and that an infinite given quantity; when we talk of divers spaces, we mean only parts of one and the same space. We conceive of space as having three dimensions, within which are contained all objects which can appear to us externally. Geometry is a science which determines the property of space synthetically.

When a single point moves it describes a line and the shortest distance between two points is a straight line; a representation of space in one direction. Points are conceived of as having position without magnitude, and lines as having length without breadth or thickness. A straight line may be divided into any number of shorter lines and one of these may be chosen as a unit by which other lines may be measured in terms of that unit.

**Standard of Length.**—The British standard yard is defined by law as "the distance between the centers of the transverse lines in the two gold plugs in the bronze bar deposited in the office of the Exchequer" at the temperature of 62° F. An authorized copy of this standard is deposited at Washington. This standard yard has been subdivided into three equal parts, one of which is called a foot; and into 36 equal parts, one of which is called an inch.

**The Metric System** is based upon an authorized standard of length called a meter, which consists in that distance, at the temperature of melting ice, between the ends of a platinum rod preserved in the French Archives, Paris. An authorized copy of this standard meter has been deposited at Washington. The metric system of measurement of length is decimal.

The equivalent length of a meter in British measurements as adopted by the United States is as follows:

| | | |
|---|---|---|
| Meter | = 39.37000 inches, or ................ | 1 inch = 0.02540 meter. |
| | = 3.28083 feet, or ................ | 1 foot = 0.30480 meter. |
| | = 1.09361 yards, or ................ | 1 yard = 0.91440 meter. |

**Mass.**—The mass of a body is the quantity of matter which it contains; it must be carefully distinguished from weight. Mass is a constant quantity, whilst weight varies with the force of gravity which produces it. Weight varies with the latitude, being greatest at the poles and least at the equator; weight varies with different elevations above the level of the sea, but the mass of a body is its own property, it is the same under all circumstances, it is unaffected by change of latitude or by altitude.

We are accustomed in commercial transactions to employ mass in terms of weight, and correctly as according to Newton's Law of Gravitation, which tells us that in any locality whatever the weights of bodies are equal if their masses are equal. The earth's attraction for a body free to fall in a vacuum is subject to a constant downward acceleration of about 32.2 feet per second, at the level of the sea, latitude of London, but it is not the same at all points of the earth's surface. Inasmuch as gravity varies less than one-half per cent. within the latitudes covered by engineering practice, weights need not ordinarily be corrected for locations approximating the level of sea; but for height much above the sea level, such as mountains, the lesser weight of the atmosphere or barometric changes must be taken into account.

**The Unit of Mass** in use by English and American engineers is the British standard pound avoirdupois, an arbitrary standard consisting of a certain piece of platinum deposited in the office of the Exchequer, an authorized copy of which is preserved at Washington. This standard pound contains 7,000 grains, a grain being the smallest unit employed in British weight.

When used for comparing or verifying other standards, it is directed to be used when the thermometer is 62° F., and the barometer at 30 inches.

Then $\dfrac{7000}{g} = \dfrac{7000}{32.2} = 217.391$ grains.

An avoirdupois ounce = 437.5 grains.

Then $\dfrac{437.5}{217.391} = 2.01$ = the British unit of force *Poundal*, equivalent to one-half ounce nearly. This unit of force does not in any way depend on local variations in the force of gravity.

For all practical purposes, the engineer's Unit of Force is the avoirdupois pound. A pound-mass equal to 32.2 British Units of Force.

The French standard of weight is the Kilogram (= 1000 grams), made of platinum, and preserved at the Archives in Paris. This standard is intended to have the same weight as a cubic decimeter of water at the temperature of its maximum density—that is, 3°.9 C.

A gram is equal to the 1000th part of a kilogram or the mass of one cubic centimeter of water at the temperature of its maximum density.

The gram is chosen as a unit in the C.G.S. System.

## C. G. S. SYSTEM

The fundamental units in this system, recommended by the British Association and accepted as the standards of references throughout the scientific world, are: a definite length, centimeter (C); a definite mass, gram (G); a definite interval of time, second (S). These standards of length, mass, and time are permanent and do not change with lapse of time.

The reason for selecting the *centimeter* and the gram, rather than the *meter* and the gram, is that since a gram of water has a volume of approximately one cubic centimeter, the selection of the centimeter makes the density of water unity; whereas the selection of the meter would make it a million, and the density of a substance would be a million times its specific gravity, instead of being identical with its gravity, as in the C. G. S. System.

The adoption of one common scale for all quantities involves the frequent use of very large and very small numbers. Such numbers are most conveniently written by expressing them as the product of two factors, one of which is a power of 10, and it is usually advantageous to effect the resolution in such a way that the exponent of the power of 10 shall be characteristic of the logarithm of this number.

Thus: 3,240,000,000 will be written $3.24 \times 10^9$, and 0.00000324 will be written $3.24 \times 10^{-6}$.

The value of the meter in British inches, adopted by the *Bureau International des Poids et Mesures*, is 39.3699. This makes

1 yard = 91.4404 centimeters.
1 foot = 30.4801 centimeters.
1 inch = 2.5400 centimeters.

The standard pound = 453.59 grams, which gives
1 kilogram = 2.20463 pounds.

This is in practical correspondence with the units legalized in the United States.

By Act of Congress, July 28, 1866, the legal equivalent of 1 meter = 39.37 inches. This makes

1 yard = 91.4402 centimeters.
1 foot = 30.4801 centimeters.
1 inch = 2.54001 centimeters.

A variation from the International Metric System so slight as to make little difference whether American or European units or products are employed.

## MECHANICAL AND GEOMETRICAL QUANTITIES

The fundamental units are abbreviated thus: L = length, M = mass, T = time.

Example, Area = $L^2$, Volume = $L^3$, Velocity = $\frac{L}{T}$, Acceleration = $\frac{L}{T^2}$, Momentum = $\frac{M\,L}{T}$, Density = $\frac{M}{L^3}$, density being defined as mass per unit volume. Force = $\frac{M\,L}{T^2}$, since a force is measured by the momentum which it generates per unit of time, and is therefore the quotient of momentum by time. Or, since a force is measured by the product of a mass by the acceleration generated in this mass.

Work = $\frac{M\,L^2}{T^2}$, being the product of force and distance.

Kinetic Energy = $\frac{M\,L^2}{T^2}$ being half the product of mass by the square of velocity. The constant factor ½ can be omitted, as not affecting dimensions.

Torque, or Moment of Couple = $\frac{M\,L^2}{T^2}$, being the product of a force by a length.

The Dimensions of Angle, when measured by $\frac{\text{arc}}{\text{radius}}$ are zero. The same angle will be denoted by the same number whatever be the unit of length employed. In fact, we have $\frac{\text{arc}}{\text{radius}} = \frac{L}{L} = L^\circ$.

The work done by a torque in turning a body through any angle is the product of

the torque by the angle. The identity of dimensions between work and torque is thus verified.

Angular Velocity $= \frac{1}{T}$.

Angular Acceleration $= \frac{1}{T^2}$.

Moment of Inertia $= M\,L^2$.

Angular Momentum = Moment of Momentum $= \frac{M\,L^2}{T}$, being the product of moment of inertia by angular velocity, or the product of momentum by length.

*Intensity of pressure*, or *intensity of stress* generally, being a force per unit of area, is of dimensions $\frac{\text{force}}{\text{area}}$, that is, $\frac{M}{L\,T^2}$.

Intensity of force of *attraction at a point*, often called simply *force at a point*, being force per unit of attracted mass, is of dimensions $\frac{\text{force}}{\text{mass}}$ or $\frac{L}{T^2}$. It is numerically equal to the acceleration which it generates, and has accordingly the dimensions of acceleration.

*Curvature* (of a curve) $= \frac{1}{L}$, being the angle turned by the tangent per unit distance travelled along the curve.

Tortuosity $= \frac{1}{L}$, being the angle turned by the osculating plane per unit distance travelled along the curve.—*J. D. Everett.*

## C. G. S. MECHANICAL UNITS

**Value of g.** Velocity is the rate of motion. It is either uniform or variable. When variable, the rate at which it changes is called acceleration if the velocity is increasing, and retardation if it is diminishing. The C. G. S. unit of acceleration is the acceleration of a body whose velocity increases in every second by the C. G. S. unit of velocity —namely, by a centimeter per second. The apparent acceleration of a body falling freely under the action of gravity in vacuo is denoted by $g$. The value of $g$ in C. G. S. units is about 978 at the equator, about 983 at the poles, and about 981 at Paris or London. The value at sea level and latitude 45° employed by the Bureau of Standards is $g = 980.665$ dynes.

**Unit of Force.**—The C. G. S. unit of force is called the *dyne*. It is the force which, acting upon a gram of matter for a second, generates a velocity of a centimeter per second. The dyne is about 1.02 times the weight of a milligram at any part of the earth's surface; and the megadyne is about 1.02 times the weight of a kilogram.

The force represented by the *weight of a gram* varies from place to place. To compute its amount in dynes at any place where $g$ is known, observe that a mass of one gram falls in vacuo with acceleration $g$. The weight (when weight means force) of one gram is therefore $g$ dynes, and the weight of $m$ grams is $m\,g$ dynes. The weight of a gram at any part of the earth's surface is about 980 dynes.

Force is said to be expressed in *gravitation measure* when it is expressed as equal to the weight of a given mass. Such specification is inexact unless the value of $g$ is also given. For purposes of accuracy it must always be remembered that the pound, the gram, etc., are, strictly speaking, units of mass.

**Poundal.**—The name *poundal* has been given to the unit force based on the pound, foot, and second; that is, the force which, acting on a pound for a second, generates a velocity of a foot per second. It is $\frac{1}{g}$ of the weight of a pound, $g$ denoting the accelera-

tion due to gravity expressed in foot-second units, which is about 32.2 feet per second, at the level of the sea, latitude of London.

To compare the poundal with the dyne, let $x$ denote the number of dynes in a poundal; we then have

$$x = \frac{\text{gm. cm.}}{\text{sec}^2} = \frac{\text{lb. ft.}}{\text{sec}^2}.$$

$$x = \frac{\text{lb.}}{\text{gm.}} \cdot \frac{\text{ft.}}{\text{cm.}} = 453.59 \times 30.4801 = 13{,}825.$$

**Unit of Momentum** is the momentum of a gram moving with the velocity of a centimeter per second.

**Unit of Work.**—The C. G. S. unit of work is called the *erg*. It is the amount of work done by a dyne working through a distance of a centimeter. The gram-centimeter is about 980 ergs. The kilogrammeter is about 98,000,000 ergs.

**Unit of Energy.**—The C. G. S. unit of energy is also the erg, energy being measured by the amount of work which it represents.

**Unit of Power.**—The C. G. S. unit of power is the power of doing work at the rate of one erg per second; and the power of an engine, under given conditions of working, can be specified in ergs per second.

**Gravitation Units of Work.**—Work, like force, is often expressed in gravitation measures, such as the foot, pound and kilogrammeter, these varying with locality, being proportional to the value of $g$.

1 gram-centimeter = $g$ ergs.
1 kilogrammeter = 100,000 $g$ ergs.
1 foot-poundal = $453.59 \times (30.4801)^2 = 421{,}401$ ergs.
1 foot-pound = 13,823 gram-centims., which, if $g = 981 = 1.356 \times 10^7$ ergs.
1 joule = $10^7$ ergs.

**Work-rate, or Activity.**—The time rate of doing work in the C. G. S. System is one erg per second. A horsepower is defined as 550 foot-pounds per second. This is $7.46 \times 10^9$ ergs per second. A cheval is defined as 75 kilogrammeters per second. This is $7.36 \times 10^9$ ergs per second. The value of $g = 981$.

**Watt.**—A work-rate of $10^7$ C. G. S. is called a watt, and 1,000 watts make a kilowatt.

1 watt = $10^7$ ergs per second = .00134 horsepower = .737 foot-pounds per second = .1019 kilogrammeters per second.
1 kilowatt = 1.34 horsepower.
1 horsepower = 550 foot-pounds per second = 76.0 kilogrammeters per second = 746 watts = 1.01385 cheval = .746 kilowatt.
1 cheval = 75 kilogrammeters per second = 542.48 foot-pounds per second = 736 watts = .9863 horsepower = .736 kilowatt.

**Calorie.** Engineers commonly reckon the heat value of fuels in terms of *kilogram-calories*. The kilogram calorie represents the energy required to raise the temperature of one kilogram of cold water one degree Centigrade; this is equivalent to raising one kilogram to a height of about 427 meters. The kilogram-calorie is sometimes called the kilogram-degree, as well as the major calorie.

The heat unit employed in physical and chemical laboratories is a metric unit also called a calorie; it is the heat required to raise the temperature of a gram of cold water one degree Centigrade. This is the *gram-degree* or minor calorie.

In the C. G. S. System the primary unit of heat in calorimetry is the *erg*. In this system the unit of force is called the *dyne;* the force which, acting upon a gram for a second, generates a velocity of a centimeter per second. This work unit is called a dyne-centimeter, which, for convenience, has been shortened to erg. Since the erg is a very small unit of work, the joule = $10^7$ ergs is often used. But it is the practice to employ a secondary rather than the primary unit of heat, and this unit is called a *therm*. It has the same value as the gram-degree, or the *minor calorie*, given above. The kilogram-degree, or *major calorie*, is equal to 1,000 therms. The pound-degree Cent. is 453.6 therms, and the pound-degree Fahr. is 252.0 therms.

The ratio of the secondary to the primary unit of heat is commonly called the

"mechanical equivalent of heat," quite often "Joule's equivalent," and is denoted by the symbol J. It is the number of units of work required to raise the temperature of unit mass of water 1°. In the C. G. S. System it is the number of ergs in a therm.

The following values of J will be useful for reference. Taking $g$ as 981,

| | |
|---|---|
| 1 kilogram-degree | = 1000 therms. |
| | = 426.5 kilogrammeters. |
| 1 pound-degree Cent. | = 453.6 therms. |
| | = 1399.4 foot-pounds. |
| 1 pound-degree Fahr. | = 252.0 therms. |
| | = 777.4 foot-pounds. |

Taking $g$ as 981.2, its value at Greenwich, these values of J are changed to

426.42, 1399.1, 777.3.

At Edinburgh, taking $g$ as 981.6, they will be

426.67, 1399.9, 777.7

In latitude 45°, taking $g$ as 980.62, they will be

426.67, 1399.9, 777.7.

**Unit of Heat.** The British thermal unit of heat (B.t.u.) is the amount of heat required to raise the temperature of 1 lb. of water 1° Fahr. when at or near its greatest density (39.1° F.). This is sometimes called the pound-degree Fahrenheit unit.

In the pound-degree Centigrade unit the avoirdupois pound and the Centigrade scale of temperature are used.

The mechanical equivalent of heat as experimentally determined by Joule was found to equal 772 foot-pounds for one degree Fahr., or 1,390 foot-pounds for a degree Cent., communicated to one pound of water at its greatest density. In honor of Joule, the mechanical equivalent of heat is usually denoted by the letter J.

Recent investigations by Rowland and others have led to the conclusion that 778 is a more nearly correct value (about $\frac{3}{4}$ of 1 per cent greater) and that

1 B.t.u. = 778 foot-pounds = J.

In engineering calculations, the former equivalent gives

$$1 \text{ horsepower} = \frac{33{,}000}{772} = 42.74 \text{ thermal units.}$$

The later equivalent gives

$$1 \text{ horsepower} = \frac{33{,}000}{778} = 42.42 \text{ thermal units.}$$

## UNITS OF MEASUREMENT AND DERIVED UNITS IN USE IN GREAT BRITAIN AND THE UNITED STATES

The fundamental units of length and mass employed in engineering work are not commonly those of the C. G. S. System. In the United States the same units are employed as in Great Britain; the unit of length being the yard, or, for convenience, a subdivision of the yard as foot or inch. The unit of mass is the avoirdupois pound. The unit of time is the second. The following dimensional formulæ are from the Smithsonian Physical Tables.

**Derived Units.** Units of quantities depending on powers greater than unity of the fundamental length, mass and time units, or on combinations of different powers of these units, are called "derived units." Thus, the units of area and volume are respectively the area of a square whose side is the units of length and the volume of a cube whose edge is the unit of length. Suppose that the area of a surface is expressed in terms of the foot as fundamental unit, and we wish to find the area-number when the yard is taken as fundamental unit. The yard is three times as long as the foot, and therefore the area of a square whose side is a yard is $3 \times 3$ times as great as that whose side is a foot.

**Dimensional Formulæ.** It is convenient to adopt symbols for the ratio of length units, mass units and time units, and adhere to their use throughout, and to what

follows the small letters $l$, $m$, $t$, will be used for these ratios. These letters will always represent simple numbers, but the magnitude of the number will depend upon the relative magnitude of the units, the ratio of which they represent. When the values of the numbers represented by $l$, $m$, $t$, are known, and the powers of $l$, $m$, $t$, involved in any particular are also known, the factor for transformation is at once obtained.

**Conversion Factors.** In order to determine the symbolic expression for the conversion factor for any physical quantity, it is sufficient to determine the degree to which the quantities, length, mass and time are involved in the quantity. Thus, a velocity is expressed by the ratio of the number representing a length to that representing an interval of time, or $\frac{L}{T}$, an acceleration by a velocity-number divided by an interval of a time-number, or $\frac{L}{T^2}$, and so on, and the corresponding ratios of units must, therefore, enter to precisely the same degree. The factors would thus be for the above cases, $\frac{l}{t}$ and $\frac{l}{t^2}$. Equations of the form above given for velocity and acceleration which show the dimensions of the quantity in terms of the fundamental units are called "dimensional equations."

**Area.**—The unit of area is the square the side of which is measured by the unit of length. The area of a surface is therefore expressed as $S = CL^2$, where C is a constant depending on the shape of the boundary of the surface and L a linear dimension. For example, if the surface be a square and L be the length of a side, C is unity. If the boundary be a circle and L be a diameter, $C = \frac{\pi}{4}$, and so on. The dimensional formula is thus $L^2$, and the conversion factor $l^2$.

**Volume.**—The unit of volume is the volume of a cube the edge of which is measured by the unit of length. The volume of a body is therefore expressed as $V = CL^3$ where, as before, C is a constant depending on the slope of the boundary. The dimensional formula is $L^3$ and the conversion factor is $l^3$.

**Density.**—The density of a substance is the quantity of matter in the unit of volume. The dimension formula is therefore $\frac{M}{V}$ or $M\,L^{-3}$, and conversion factor $m\,l^{-3}$.

NOTE.—The specific gravity of a body is the ratio of its density to the density of a standard substance. The dimension formula and conversion factor are therefore both unity.

**Velocity.**—The velocity of a body at any instant is given by the equation $v = \frac{dL}{dT}$, or velocity is the ratio of a length-number to a time-number. The dimensional formula $L\,T^{-1}$, and conversion factor $l\,t^{-1}$.

**Angle.**—Angle is measured by the ratio of the length of an arc to the length of the radius of the arc. The dimension formula and the conversion factor are therefore both unity.

**Angular Velocity.**—Angular velocity is the ratio of the magnitude of the angle described in an interval of time to the length of the interval. The dimension formula is therefore $T^{-1}$, and the conversion factor is $t^{-1}$.

**Linear Acceleration.**—Acceleration is the rate of change of velocity or $a = \frac{dv}{dt}$. The dimension formula is therefore $VT^{-1}$ or $LT^{-2}$, and the conversion factor is $l\,t^{-2}$.

**Angular Acceleration.**—Angular acceleration is the rate of change of angular velocity. The dimensional formula is thus $\frac{\text{angular velocity}}{T}$ or $T^{-2}$, and the conversion factor is $t^{-2}$.

**Solid Angle.**—A solid angle is measured by the ratio of the surface of the portion

of a sphere inclosed by the conical surface forming the angle to the square of radius of the radius of the spherical surface, the center of the sphere being at the vertex of the cone. The dimensional formula is therefore $\frac{\text{area}}{L^2}$ or 1, and hence the conversion factor is also 1.

**Curvature.**—Curvature is measured by the rate of change of direction of the curve with reference to distance measured along the curve as independent variable. The dimension formula is therefore $\frac{\text{angle}}{\text{length}}$ or $L^{-1}$, and the conversion factor is $l^{-1}$.

**Tortuosity.**—Tortuosity is measured by the rate of rotation of the tangent plane round the tangent, to the curve of reference when length along the curve is independent variable. The dimension formula is therefore $\frac{\text{angle}}{\text{length}}$ or $L^{-1}$, and the conversion factor is $l^{-1}$.

**Specific Curvature of a Surface.**—This was defined by Gauss to be at any point of the surface, the ratio of the solid angle enclosed by a surface formed by moving a normal to the surface round the periphery of a small area containing the point, to the magnitude of the area. The dimensional formula is therefore $\frac{\text{solid angle}}{\text{surface}}$ or $L^{-2}$, and the conversion factor is $l^{-2}$.

**Momentum.**—This is the quantity of motion in the Newtonian sense, and is, at any instant, measured by the product of the mass-number and the velocity-number for the body. Thus, the dimension formula is $M\,V$ or $M\,L\,T^{-1}$ and the conversion factor $m\,l\,t^{-1}$.

**The Moment of Momentum.**—The moment of momentum of a body with reference to a point is the product of its momentum-number and the number expressing the distance of its line of motion from the point. The dimensional formula is thus $M\,L^2\,T^{-1}$ and hence the conversion factor is $m\,l^2\,t^{-1}$.

**Moment of Inertia.**—The moment of inertia of a body round any axis is expressed by the formula $\Sigma\, m\, r^2$, where $m$ is the mass of any particle of the body and $r$ its distance from the axis. The dimension formula for the sum is clearly the same as for each element and hence is $M\,L^2$. The conversion factor is therefore $m\,l^2$.

**Angular Momentum.**—The angular momentum of a body round any axis is the product of the numbers expressing the moment of inertia and the angular velocity of the body. The dimensional formula and the conversion factor are therefore the same as for moment of momentum given above.

**Force.**—A force is measured by the rate of change of momentum it is capable of producing. The dimension formulæ for force and "time-rate of change of momentum" are therefore the same and are expressed by ratio of momentum-number to time-number or $M\,L\,T^{-2}$. The conversion factor is thus $m\,l\,t^{-2}$.

NOTE.—When mass is expressed in pounds, length in feet, and time in seconds, the unit of force is called the poundal. When grams, centimeters, and seconds are the corresponding units, the unit of force is called the dyne.

**Moment of a Couple, Torque or Twisting Motive.**—These are different names for a quantity which can be expressed as the product of two numbers representing a force and a length. The dimension formula is therefore $F\,L$ or $M\,L^2\,T^{-2}$, and the conversion factor is $m\,l^2\,t^{-2}$.

**Intensity of a Stress.**—The intensity of a stress is the ratio of a number expressing the total stress to the number expressing the area over which the stress is distributed. The dimensional formula is thus $F\,L^{-2}$ or $M\,L^{-1}\,T^{-2}$, and the conversion factor is $m\,l^{-1}\,t^{-2}$.

**Intensity of Attraction, or "Force at a Point."**—This is the force of attraction per unit mass on a body placed at the point, and the dimensional formula is therefore $F\,M^{-1}$ or $L\,T^{-2}$, the same as acceleration. The conversion factors for acceleration therefore apply.

**Absolute Force of a Center of Attraction, or "Strength of a Center."**—This is the intensity of force at unit distance from the center and is, therefore, the force per unit-mass at any point multiplied by the square of the distance from the center. The dimensional formula thus becomes $F L^2 M^{-1}$ or $L^3 T^{-2}$. The conversion factor is therefore $l^3 t^{-2}$.

**Modulus of Elasticity.**—A modulus of elasticity is the ratio of stress intensity to percentage strain. The dimension of percentage strain is a length divided by a length, and is therefore unity. Hence the dimensional formula of a modulus of elasticity is the same as that of stress intensity, or $M L^{-1} T^{-2}$, and the conversion factor is thus also $m l^{-1} t^{-2}$.

**Work and Energy.**—When the point of application of a force acting on a body moves in the direction of the force, work is done by the force, and the amount is measured by the product of the force and displacement number. The dimensional formula is therefore $F L$ or $M L^2 T^{-2}$. The work done by the force either produces a change in the velocity of the body, or a change of shape or configuration of the body, or both. In the first case it produces a change of kinetic energy, in the second a change of potential energy. The dimension formulæ of energy and work representing quantities of the same kind are identical and the conversion factor for both is $m l^2 t^{-2}$.

**Resilience.**—This is the work done per unit-volume of a body in distorting it to the elastic limit, or in producing rupture. The dimension formula is therefore $M L^2 T^{-2} L^{-3}$ or $M L^{-1} T^{-2}$, and the conversion factor is $m l^{-1} t^{-2}$.

**Power, or Activity.**—Power—or, as it is now very commonly called, activity—is defined as the time-rate of doing work, or, if W represents work and P power, $P = \frac{dw}{dt}$. The dimensional formula is therefore $W T^{-1}$ or $M L^2 T^{-3}$ and the conversion factor $m l^2 t^{-3}$, or for problems in gravitation-units, more conveniently $f l t^{-1}$, where $f$ stands for force factor.

Example 1.—Find the number of gram-centimeters in one foot-pound. Here the units of force are the attraction of the earth on the pound and the gram of matter, and the conversion factor is $f l$, where $f$ is 453.59 and $l$ is 30.48.

Hence the number is $453.59 \times 30.48 = 13{,}825$.

Note.—It is important to remember that in problems like that here given the terms "pound" or "gram" refer to force and not to mass.

2. If gravity produces an acceleration of 32.2 feet per second per second, how many watts are required to make one horse-power?

One horse-power is 550 foot-pounds per second, or $550 \times 32.2 = 17{,}710$ foot-poundals per second. One watt is $10^7$ ergs per second, that is, $10^7$ dyne-centimeters per second. The conversion factor is $m l^2 t^{-3}$, where $m = 453.59$, $l = 30.48$, and $t = 1$, and the result has to be divided by $10^7$, the number of dyne-centimeters per second in the watt.

Hence, $17{,}710\, m l^2 t^{-3} \div 10^7 = 17{,}710 \times 453.59 \times 30.48^2 \div 10^7 = 746.3$.

3. How many gram-centimeters per second correspond to 33,000 foot-pounds per minute?

The conversion factor suitable for this case is $f l t^{-1}$, where $f$ is 453.59, $l$ is 30.48, and $t$ is 60.

Hence, $33{,}000\, l t^{-1} = 33{,}000 \times 453.59 \times 30.48 \div 60 = 7{,}604{,}000$, nearly.

## HEAT UNITS

If heat be measured in dynamical units its dimensions are the same as those of energy, namely, $M L^2 T^{-2}$. The most common measurements, however, are made in thermal units, that is, in terms of the amount of heat required to raise the temperature of unit mass of water one degree of temperature at some stated temperature. This method of measurement involves the unit of mass and some unit of temperature, and hence if we denote temperature-numbers by $\Theta$ and their conversion factors by $\theta$, the dimensional formula and conversion factor for quantity of heat will be $M\Theta$ and $m\theta$ respectively. The relative amount of heat compared with water as standard substance

required to raise unit mass of different substances one degree in temperature is called their specific heat and is a simple number.

Unit volume is sometimes used instead of unit mass in the measurement of heat, the units being then called thermometric units. The dimensional formula is in that case changed by the substitution of volume for mass and becomes $L^3\Theta$, and here the conversion factor is to be calculated from the formula $l^3\theta$.

**Coefficient of Expansion.**—The coefficient of expansion of a substance is equal to the ratio of the change of length per unit length (linear) or change of volume per unit volume (voluminal) to the change of temperature. These ratios are simple numbers, and the change of temperature is inversely as the magnitude of the unit of temperature. Hence, the dimensional and conversion-factor formulæ are $\Theta^{-1}\,\theta^{-1}$.

**Conductivity, or Specific Conductance.**—This is the quantity of heat transmitted per unit of time per unit of surface per unit of temperature gradient. The equation for conductivity is therefore with H as quantity of heat $K = \dfrac{H}{\frac{\Theta}{L} L^2 T}$ and the dimensional formula $\dfrac{H}{\Theta L T} = \dfrac{M}{L T}$, which gives $m\,l^{-1}\,t^{-1}$ for conversion factor.

In thermometric units the formula becomes $L^2\,T^{-1}$, which properly represents diffusivity. In dynamical units H becomes $M\,L^2\,T^{-2}$ and the formula changes to $M\,L\,T^{-3}\,\Theta^{-1}$. The conversion factors obtained from these are $l^2\,t^{-1}$ and $m\,l\,t^{-3}\,\theta^{-1}$ respectively.

Similarly, for emission and absorption we have:

**Emissivity and Immissivity.**—These are the quantities of heat given off by or taken in by the body per unit of time per unit of surface per unit difference of temperature between the surface and the surrounding medium. We thus get the equation $E\,L^2\,\Theta\,T = H = M\,\Theta$. The dimensional formula for E is therefore $M\,L^{-2}\,T^{-1}$, and conversion factor $m\,l^{-2}\,t^{-1}$. In thermometric units by substituting $l^5$ for $m$ the factor becomes $l\,t^{-1}$, and in dynamical units $m\,t^{-3}\,\theta^{-1}$.

**Thermal Capacity.**—This is the product of the number for mass and the specific heat, and hence the dimensional formula and conversion factor are simply M and $m$.

**Latent Heat.**—Latent heat is the ratio of the number representing the quantity of heat required to change the state of a body to the number representing the quantity of matter in the body. The dimensional formula is therefore, $\dfrac{M\,\Theta}{M}$ or $\Theta$, and hence the conversion factor is simply the ratio of the temperature units or $\theta$. In dynamical units the factor is $l^2\,t^{-2}$.

Note.—When $\Theta$ is given the dimension formula $L^2\,T^{-2}$, the formulæ in thermal and dynamical units are always identical. The thermometric units practically suppress mass.

**Joule's Equivalent.**—Joule's dynamical equivalent is connected with quantity of heat by the equation $M\,L^2\,T^{-2} = J\,H$ or $J\,M\,\Theta$.

This gives for the dimensional formula of J the expression $L^2\,T^{-2}\,\Theta$. The conversion factor is thus represented by $l^2\,t^{-2}\,\theta$. When heat is measured in dynamical units J is a simple number.

**Entropy.**—The entropy of a body is directly proportional to the quantity of heat it contains and inversely proportional to its temperature. The dimensional formula is thus $\dfrac{M\,\Theta}{\Theta}$ or M, and the conversion factor is $m$. When heat is measured in dynamical units the factor is $m\,l^2\,t^{-2}\,\theta^{-1}$.

Example.—Find the relation between the British thermal unit, the calorie and the therm.

Neglecting the variation of the specific heat of water with temperature, or defining all the units for the same temperature of the standard substance, we have the following definitions: The *British thermal unit* is the quantity of heat required to raise the

temperature of one pound of water 1° F. The *calorie* is the quantity of heat required to raise the temperature of one kilogram of water 1° C. The *therm* is the quantity of heat required to raise the temperature of one gram of water 1° C. Hence:

To find the number of calories in one British thermal unit, we have $m = .45399$ and $\theta = \frac{5}{9}$; $\therefore\ m\,\theta = .45399 \times \frac{5}{9} = .25199$.

To find the number of therms in a calorie, $m = 1{,}000$ and $\theta = 1$; $\therefore\ m\,\theta = 1{,}000$.

It follows at once that the number of therms in one British thermal unit is $1{,}000 \times .25199 = 251.99$.

If Joule's equivalent be 776 foot-pounds per pound of water per degree Fahr., what will be its value in gravitation units when the meter, the kilogram and the degree Cent. are units?

The conversion factor in this case is $\frac{l^2\,t^{-2}\,\theta}{l\,t^{-2}}$ or $l\,\theta$, where $l = .3048$ and $\theta = 1.8$; $\therefore\ 776 \times .3048 \times 1.8 = 425.7$.

If Joule's equivalent be 24,832 foot-poundals when the degree Fahr. is unit of temperature, what will be its value when kilogrammeter-second and degree-Centigrade units are used?

The conversion factor is $l^2\,t^{-2}\,\theta$, where $l = .3048$, $t = 1$, and $\theta = 1.8$; $\therefore$ $24{,}832 \times l^2\,t^{-2}\,\theta = 24{,}832 \times .3048^2 \times 1.8 = 4{,}152.5$.

In gravitation units this would give $\frac{4{,}152.5}{9.81} = 423.3$.

## FUNDAMENTAL AND DERIVED UNITS OF LENGTH, MASS, TIME, AND TEMPERATURE

| | | Symbol | Conversion factor |
|---|---|---|---|
| **Fundamental:** | Length | L | $l$ |
| | Mass | M | $m$ |
| | Time | T | $t$ |
| | Temperature | Θ | $\theta$ |

## GEOMETRIC AND DYNAMIC UNITS

| | | Conversion factor |
|---|---|---|
| **Derived:** | Area | $l^2$ |
| | Volume | $l^3$ |
| | Angle | 1 |
| | Solid Angle | 1 |
| | Curvature | $l^{-1}$ |
| | Tortuosity | $l^{-1}$ |
| | Specific Curvature of a Surface | $l^{-2}$ |
| | Angular Velocity | $l^{-1}$ |
| | Angular Acceleration | $l\,t^{-2}$ |
| | Linear Velocity | $l\,t^{-1}$ |
| | Linear Acceleration | $l\,t^{-2}$ |
| | Density | $m\,l^{-3}$ |
| | Moment of inertia | $m\,l^2$ |
| | Intensity of attraction, or "force at a point" | $l\,t^{-2}$ |
| | Absolute force of a center of attraction, or "strength of a center" | $l^3\,t^{-2}$ |
| | Momentum | $m\,l\,t^{-1}$ |
| | Moment of momentum, or angular momentum | $m\,l^2\,t^{-1}$ |
| | Force | $m\,l\,t^{-2}$ |
| | Moment of a couple, or torque | $m\,l^2\,t^{-2}$ |
| | Intensity of stress | $m\,l^{-1}\,t^{-2}$ |
| | Modulus of elasticity | $m\,l^{-1}\,t^{-2}$ |
| | Work and energy | $m\,l^2\,t^{-2}$ |
| | Resilience | $m\,l^{-1}\,t^{-2}$ |
| | Power, or activity | $m\,l^2\,t^{-3}$ |

## HEAT UNITS

| | | |
|---|---|---|
| **Derived:** | Quantity of heat (thermal units) . . . **Conversion factor:** | $m\,\theta$ |
| | Quantity of heat (thermometric units) | $l^3\,\theta$ |
| | Quantity of heat (dynamical units) | $m\,l^2\,t^{-2}$ |
| | Coefficient of thermal expansion | $\theta^{-1}$ |
| | Conductivity (thermal units) | $m\,l^{-1}\,t^{-1}$ |
| | Conductivity (thermometric units), or diffusivity | $l^2\,t^{-1}$ |
| | Conductivity (dynamical units) | $m\,l\,t^{-3}\,\theta^{-1}$ |
| | Emissivity and imissivity (thermal units) | $m\,l^{-2}\,t^{-1}$ |
| | Emissivity and imissivity (thermodynamic units) | $l\,t^{-1}$ |
| | Emissivity and imissivity (dynamical units) | $m\,t^{-3}\,\theta^{-1}$ |
| | Thermal capacity | $m$ |
| | Latent heat (thermal units) | $\theta$ |
| | Latent heat (dynamical units) | $l^2\,t^{-2}$ |
| | Joule's equivalent | $l^2\,t^{-2}\,\theta$ |
| | Entropy (heat measured in thermal units) | $m$ |
| | Entropy (heat measured in dynamical units) | $m\,l^2\,t^{-2}\,\theta$ |

## UNITED STATES UNITS AND STANDARDS

The weights and measures in common use in the United States are an inheritance from the Colonial period, therefore in substantial agreement with those of Great Britain; certain variations occur such as the gallon and the bushel, which will be explained further on.

Conformably to a resolution passed by the U. S. Senate in 1830, the Secretary of the Treasury ordered a comparison of the weights and measures in use at the principal custom houses to be made, and appointed F. R. Hassler, Superintendent of the U. S. Coast Survey, to make the investigation and report. A preliminary report was made in 1831, followed by a more complete report the year following. As was anticipated, large discrepancies were found, but the average value of the different denominations agreed fairly well with those in use in Great Britain at the time of the American Revolution. Mr. Hassler was instructed to correct this irregularity by the construction of uniform weights and measures for the customs service. With the exception of the troy pound-weight, Congress had legalized no system of units of weights and measures.

The avoirdupois pound adopted by Mr. Hassler as the standard for the Treasury Department was derived from the troy pound of the U. S. Mint according to the equivalent 1 avoirdupois pound equals $\frac{7{,}000}{5{,}760}$ pounds troy. This was the accepted relation in this country as well as in England.

The standard yard of 36 inches, copied from the English yard, was incorporated as the standard unit of length.

Two units of capacity, the wine gallon of 231 cubic inches and the Winchester bushel of 2,150.42 cubic inches, were adopted because they represented more closely than any other English standards the average capacity measures in use in the United States at the date of Mr. Hassler's investigation.

These were the fundamental standards adopted upon the recommendation of Mr. Hassler by the U. S. Treasury Department, and to which the weights and measures for the customs service were made to conform.

## AIR AS A STANDARD

The atmosphere varies in density from practically nothing, where it shades off into space, to that produced by a pressure of 14.7 lbs. at the level of the sea, which we call atmospheric pressure. The height of the atmosphere has never been measured, but observations of the duration of twilight, which is due to reflection from particles of dust and air, give about 50 miles as the limit.

| | | | |
|---|---|---|---|
| 1 atmosphere | = | 14.697 | pounds per square inch (14.7). |
| 1 pound per square inch | = | .0680 | atmosphere. |
| 1 pound pressure per sq. in. | = | 27.72 | inches or 2.31 feet high of water at 62° F. |
| 1 pound pressure per sq. in. | = | 1891 | feet high of air of uniform density at sea level and 62° F. |
| 1 lb. pressure per sq. in. 32° F. | = | 2.035 | inches high of mercury or 51.7 millimeters. |
| 1 lb. pressure per sq. in. 62° F. | = | 2.04 | inches high of mercury. |
| 1 atmosphere 32° F. | = | 29.921 | inches high of mercury. |
| 1 inch height of mercury | = | .0334 | atmosphere, 32° F. |
| 1 atmosphere 62° F. | = | 30 | inches high of mercury. |
| 1 inch height of mercury | = | .0333 | atmosphere, 62° F. |
| 1 atmosphere | = | 2116.35 | pounds per square foot. |
| 1 pound per square foot | = | .000473 | atmosphere. |
| 1 pound pressure per sq. ft. | = | .1925 | inches high of water at 62° F. |
| 1 pound pressure per sq. ft. | = | 13.13 | feet high of air of uniform density at sea level and 32° F. |
| 1 pound pressure per sq. ft. | = | .0141 | inch or .359 millimeter of mercury at sea level and 32° F. At 62° F. the height is .01417 inch. |
| 1 atmosphere | = | 33.947 | feet of water in height at 62° F. |
| 1 foot height of water at 62° F. | = | .0294 | atmosphere. |
| 1 atmosphere | = | 33.901 | feet high of water at 32° F. |
| 1 foot height of water at 32° F. | = | .0295 | atmosphere. |
| Air, dry and pure, 32° F. | = | 1.0000 | specific gravity. |
| 32° F. | = | .080728 | weight in pounds, 1 cubic foot. |
| 32° F. | = | 12.387 | vol. of 1 pound in cubic feet. |
| 62° F. | = | .94263 | specific gravity 32° = 1.000. |
| 62° F. | = | .076097 | weight of 1 cu. ft. pounds. |
| 62° F. | = | 13.141 | vol. of 1 pound in cubic feet. |
| 1 atmosphere at 32° F. | = | 27801 | feet or 5.265 miles high of uniform density, equal to that of air at the level of the sea. |
| 1 atmosphere | = | 1.0582 | short tons per square foot. |
| 1 short ton per square foot | = | .945 | atmosphere. |
| 1 atmosphere | = | .945 | long tons per square foot. |
| 1 long ton per square foot | = | 1.0584 | atmosphere. |

Weight of air compared with water at the level of the sea =

| | | | |
|---|---|---|---|
| Water at 32° F. | = | 773.2 | times the weight of air at 32° F. |
| 39° 1 | = | 773.27 | times the weight of air at 32° |
| 62° | = | 772.4 | times the weight of air at 32° |
| 62° | = | 819.4 | times the weight of air at 62° |
| 52° 3 | = | 820.0 | times the weight of air at 62° |

Weight in pounds of 1 cubic foot of air containing a standard amount of carbonic acid. English Board of Trade, Standards Department.

| Condition of Air | Temperatures in Degrees Fahrenheit | | |
|---|---|---|---|
| | 32° | 62° | 80° |
| Dry air | .08098 | .07632 | .07377 |
| Ordinary air (saturation = $\frac{2}{3}$) | .08093 | .07596 | .07313 |
| Moist air (saturation = 1) | .08080 | .07578 | .07281 |

The standard amount of carbonic acid mentioned above is 6 volumes of carbonic acid to 10,000 volumes of air.

**Metric Measurements**

| | | | |
|---|---|---|---|
| 1 atmosphere | = | 10332.9 | kilograms per square meter. |
| 1 kilogram per square meter | = | .000097 | atmosphere. |
| 1 atmosphere | = | 760.0000 | millimeters of mercury. |
| 1 millimeter of mercury | = | .001316 | atmosphere. |
| 1 atmosphere | = | 10.333 | meters high of water. |
| 1 meter high of water | = | .0969 | atmosphere. |
| 1 atmosphere | = | 1.033 | kilograms per square centimeter. |
| 1 kilogram per square centimeter | = | .969 | atmosphere. |
| 1 atmosphere | = | 1.013 | megadynes per square centimeter. |
| 1 megadyne per square centimeter | = | .9872 | atmosphere. |

One liter of air, under one atmosphere of 760 millimeters, at 0° Centigrade, at sea level, weighs 1.293 grams, or 19.955 grains.

The collected data for dry air as given in C. G. S. System by Professor Everett is:

| | |
|---|---|
| Expansion from 0° to 100° C. at constant pressure as.... | 1 to 1.367 |
| Specific heat at constant pressure.................... | 0.238 |
| Specific heat at constant volume...................... | 0.170 |
| Pressure-height at 0° C. about $7.99 \times 10^5$ cm., or about.. | 26210.000 ft. |
| Standard barometric column, 76 cm................... | 29.922 ins. |

| | | |
|---|---|---|
| Standard pressure = | 1033.3 | grams per square centimeter. |
| or | 14.7 | pounds per square inch. |
| or | 2117.0 | pounds per square foot. |
| or | 1.0136 | $\times 10^6$ dynes per square centimeter. |
| Standard density, at 0° C. = | 0.001293 | gram per cubic centimeter. |
| or | 0.0807 | pounds per cubic foot. |
| Standard bulkiness | 773.0 | cubic centimeters per gram. |
| or | 12.39 | cubic foot per pound. |

**Specific Heat of Air.**—The specific heat of air is the ratio of the amount of heat required to raise the temperature of one pound of air through one degree at 32° F. Air, in common with other gases, has two specific heats: (1) Specific heat at constant pressure; the application of heat to air expands it: if the air is free to expand, work is done in heating the air and in overcoming the external pressure of the atmosphere; (2) if the air is confined so that its volume cannot change and heat is applied, the effect is rise in temperature, and this is called specific heat at constant volume. The former requires more hea than the latter because external work is performed in addition to the rise in temperature. When air is heated at constant volume, only internal work is done.

Regnault found the specific heat at constant pressure to be .2375 water = 1. Then, one cubic foot of air at 32° F. = .08098 pound, the reciprocal of which = 12.3487 cubic feet under one atmosphere of pressure and 32° F.

The specific heat of air at constant volume = .1689.

Ratio of the specific heats of air:

$$\frac{\text{Constant pressure, .2375}}{\text{Constant volume, .1689}} = 1.406,$$

which agrees with the values obtained indirectly from the velocity of sound. Assuming that the value 332 meters (1089 feet) per second is good for the velocity of sound, the ratio of the specific heats must be near to 1.4063. According to the Smithsonian Physical Tables, 1.4065 may be taken as fairly representing our present knowledge of the subject.

## WATER AS A STANDARD

Reduction factors: 1 cubic foot of water at 4° C., or 39° 2 F. = 62.4 pounds.
1 cubic inch of water = 0.0361111 pounds.
1 cubic centimeter of water at 4° C. = 1 gram.

| | | Reciprocal |
|---|---|---|
| 1 gram of water | = 15.432356 grains | 0.0647989 |
| | = 0.811532 U. S. Apoth. scruples | 1.232237 |
| | = 0.270511 U. S. Apoth. dram | 3.696707 |
| | = 0.0610234 cubic inch | 16.387163 |
| | = 0.0352740 ounce, av | 28.349492 |
| | = 0.0338138 U. S. liquid ounce | 29.573724 |
| | = 0.0321507 ounce, troy | 31.103521 |
| | = 0.00267923 pound, troy | 373.241566 |
| | = 0.00220462 pound, av | 453.592428 |

### Water as a Standard

| | | Reciprocal |
|---|---|---|
| 1 cubic inch of water | = 252.777778 grains | 0.00395604 |
| | = 16.387163 grams | 0.0610234 |
| | = 0.577778 ounce, av | 1.730769 |
| | = 0.554113 U. S. liquid ounce | 1.804688 |
| | = 0.526620 ounce, troy | 1.898901 |
| | = 0.043885 pound, troy | 22.786814 |
| | = 0.036111 pound, av | 27.692307 |
| | = 0.034632 U. S. liquid pint | 28.875000 |
| | = 0.0288326 English pint | 34.683000 |
| | = 0.017316 U. S. liquid quart | 57.750000 |
| | = 0.0163872 liter | 61.023378 |
| | = 0.0163872 kilogram | 61.023378 |
| | = 0.0144163 English quart | 69.366000 |
| | = 0.004329 U. S. gallon | 231.000000 |
| | = 0.00360408 English gallon | 277.463000 |
| | = 0.0005787 cubic foot | 1728.000000 |

### Water as a Standard

| | | Reciprocal |
|---|---|---|
| 1 pound of water | = 453.592428 grams | 0.00220462 |
| | = 27.692307 cubic inches | 0.0361111 |
| | = 15.344695 U. S. liquid ounces | 0.0651691 |
| | = 1.215278 pounds, troy | 0.822857 |
| | = 0.959041 U. S. liquid pint | 1.042708 |
| | = 0.798440 English pint | 1.252442 |
| | = 0.479520 U. S. liquid quart | 2.085417 |
| | = 0.453592 liter | 2.204622 |
| | = 0.453592 kilogram | 2.204622 |
| | = 0.399220 English quart | 2.504883 |
| | = 0.119880 U. S. gallon | 8.341667 |
| | = 0.0998054 English gallon | 10.019497 |
| | = 0.0160256 cubic foot | 62.400000 |
| | = 0.000593542 cubic yard | 1684.800000 |
| | = 0.00050000 short ton | 2000.000000 |
| | = 0.000453592 cubic meter | 2204.622341 |
| | = 0.000453592 metric ton | 2204.622341 |
| | = 0.00044643 long ton | 2240.000000 |

## CONVERSION FACTORS FOR WATER

### Water as a Standard

| | | | Reciprocal |
|---|---|---|---|
| 1 liter of water | = | 61.023378 cubic inches | 0.0163872 |
| | = | 2.679228 pounds, troy | 0.373242 |
| | = | 2.204622 pounds, av | 0.453592 |
| | = | 2.113364 U. S. liquid pints | 0.473179 |
| | = | 1.759464 English pints | 0.568354 |
| | = | 1.056681 U. S. liquid quarts | 0.946359 |
| | = | 1.000000 kilogram | 1.000000 |
| | = | 0.879732 English quart | 1.136708 |
| | = | 0.264170 U. S. gallon | 3.785434 |
| | = | 0.219933 English gallon | 4.546831 |
| | = | 0.0353145 cubic foot | 28.317016 |
| | = | 0.00130793 cubic yard | 764.559444 |
| | = | 0.00110231 short ton | 907.184872 |
| | = | 0.00100000 metric ton | 1000.000000 |
| | = | 0.00098421 long ton | 1016.047057 |

### Water as a Standard

United States Gallons

| | | | Reciprocal |
|---|---|---|---|
| 1 gallon of water | = | 231.000000 cubic inches | 0.004329 |
| | = | 10.137461 pounds, troy | 0.098644 |
| | = | 8.341667 pounds, av | 0.119880 |
| | = | 8.000000 U. S. liquid pints | 0.125000 |
| | = | 6.660324 English pints | 0.150143 |
| | = | 4.000000 U. S. liquid quarts | 0.250000 |
| | = | 3.785434 liters | 0.264170 |
| | = | 3.785434 kilograms | 0.264170 |
| | = | 3.330162 English quarts | 0.300286 |
| | = | 0.832543 English gallon | 1.201139 |
| | = | 0.133681 cubic foot | 7.480519 |
| | = | 0.00495113 cubic yard | 201.974025 |
| | = | 0.00417083 short ton | 239.760231 |
| | = | 0.00372396 long ton | 268.531457 |
| | = | 0.00378543 cubic meter | 264.170467 |
| | = | 0.00378543 metric ton | 264.170467 |

### Water as a Standard

Imperial Gallon of Great Britain

| | | | Reciprocal |
|---|---|---|---|
| 1 gallon of water | = | 277.463000 cubic inches | 0.00360408 |
| | = | 12.176472 pounds, troy | 0.0821256 |
| | = | 10.019497 pounds, av | 0.0998054 |
| | = | 9.609108 U. S. liquid pints | 0.104068 |
| | = | 8.000000 English pints | 0.125000 |
| | = | 4.804554 U. S. liquid quarts | 0.208136 |
| | = | 4.546831 liters | 0.219933 |
| | = | 4.546831 kilograms | 0.219933 |
| | = | 4.000000 English quarts | 0.250000 |
| | = | 1.201139 U. S. gallons | 0.832543 |
| | = | 0.160569 cubic foot | 6.227843 |
| | = | 0.0059470 cubic yard | 168.152150 |
| | = | 0.00500975 short ton | 199.610819 |
| | = | 0.00454477 metric ton | 220.033235 |
| | = | 0.00447299 long ton | 223.564117 |

### Water as a Standard

| | | | Reciprocal |
|---|---|---|---|
| 1 cubic foot of water | = 1728.000000 | cubic inches | 0.000578704 |
| | = 75.833333 | pounds, troy | 0.0131868 |
| | = 62.400000 | pounds, av | 0.0160256 |
| | = 59.844047 | U. S. liquid pints | 0.0167101 |
| | = 49.822679 | English pints | 0.0200712 |
| | = 29.922112 | U. S. liquid quarts | 0.0334201 |
| | = 28.317016 | liters | 0.0353145 |
| | = 28.317016 | kilograms | 0.353145 |
| | = 24.911340 | English quarts | 0.0401424 |
| | = 7.480495 | U. S. gallons | 0.133681 |
| | = 6.227857 | English gallons | 0.160569 |
| | = 0.370370 | cubic yard | 27.000000 |
| | = 0.031200 | short ton | 32.051282 |
| | = 0.0283170 | cubic meters* | 35.314455 |
| | = 0.0283042 | metric ton | 35.330486 |
| | = 0.0278571 | long ton | 35.897436 |

*This line and the one following show the relation of a cubic foot to a cubic meter figured in feet and inches, also the relation of a cubic foot of water = 1728 cubic inches weighing 62.4 pounds—to a metric ton. The figures should in both cases be alike, the difference is due to the cumulative effect of unending decimals. In the case of the metric ton we have the fractions: 1 meter = 3.280833333 feet, and 1 kilogram = 2.204-622341 pounds. Without attempting to adjust fractional differences, the recognized metric ton = 2204.622341 pounds is here employed.

### Water as a Standard

| | | | Reciprocal |
|---|---|---|---|
| 1 cubic yard of water | = 1684.800000 | pounds | 0.000593485 |
| | = 764.212640 | liters | 0.000130854 |
| | = 201.974025 | U. S. gallons | 0.00495113 |
| | = 168.152150 | English gallons | 0.00594700 |
| | = 27.000000 | cubic feet | 0.0370370 |
| | = .842400 | short tons | 1.187085 |
| | = .764213 | metric ton | 1.308536 |
| | = .752143 | long ton | 1.329534 |

### Water as a Standard

1 cubic meter of water at 4° C. = 1 metric ton

| | | | Reciprocal |
|---|---|---|---|
| 1 cubic meter of water | = 2204.622341 | pounds | 0.000453592 |
| | = 1000.000000 | liters | 0.001000000 |
| | = 1000.000000 | kilograms | 0.001000000 |
| | = 264.170467 | U. S. gallons | 0.00378543 |
| | = 219.933389 | English gallons | 0.00454683 |
| | = 35.314455 | cubic feet | 0.0283170 |
| | = 1.307943 | cubic yards | 0.764560 |
| | = 1.102311 | short tons | 0.907185 |
| | = 1.000000 | metric ton | 1.000000 |
| | = 0.984206 | long ton | 1.0160471 |

## CONVERSION FACTORS FOR WATER

### Water as a Standard

| | | | Reciprocal |
|---|---|---|---|
| 1 short ton of water | = 2000.000000 | pounds | 0.0005000 |
| | = 907.184872 | liters | 0.00110231 |
| | = 907.184872 | kilograms | 0.00110231 |
| | = 239.760231 | U. S. gallons | 0.00417083 |
| | = 199.610819 | English gallons | 0.00500975 |
| | = 32.051283 | cubic feet | 0.031200 |
| | = 1.187085 | cubic yards | 0.842400 |
| | = 0.892858 | long ton | 1.120000 |
| | = 0.907185 | metric ton | 1.102311 |

### Water as a Standard

| | | | Reciprocal |
|---|---|---|---|
| 1 long ton of water | = 2240.000000 | pounds | 0.000446429 |
| | = 1016.047057 | liters | 0.00098421 |
| | = 1016.047057 | kilograms | 0.00098421 |
| | = 268.531457 | U. S. gallons | 0.00372396 |
| | = 223.564117 | English gallons | 0.00447299 |
| | = 35.897436 | cubic feet | 0.0278571 |
| | = 1.329535 | cubic yards | 0.752143 |
| | = 1.120000 | short tons | 0.892858 |
| | = 1.016047 | metric tons | 0.984206 |

# PHYSICAL CONSTANTS OF METALS

| Metal. | Symbol. | Atomic Weight. | Atomic Volume. | Specific Gravity. | Specific Heat. | Melting Point. °C. | Coefficient of Linear Expansion. | Thermal Conductivity in cal. cm. secs. | Electrical Conductivity. Ag. = 100. |
|---|---|---|---|---|---|---|---|---|---|
| Aluminium | Al | 27·1 | 10·6 | 2·56 | 0·218 | 657 | 0·0000231 | 0·502 | 57·3 |
| Antimony | Sb | 120·2 | 17·9 | 6·71 | 0·051 | 630 | 0·0000105 | 0·042 | 4·6 |
| Arsenic | As | 75·0 | 13·2 | 5·67 | 0·081 | 450 | 0·0000055 | .. | 4·7 |
| Barium | Ba | 137·4 | 36·3 | 3·78 | 0·047 | 850 | .. | .. | 1·3 |
| Bismuth | Bi | 208·0 | 21·2 | 9·80 | 0·031 | 266 | 0·0000162 | 0·019 | 1·3 |
| Cadmium | Cd | 112·4 | 13·2 | 8·60 | 0·056 | 322 | 0·0000306 | 0·219 | 14·7 |
| Cæsium | Cs | 132·8 | 71·1 | 1·87 | 0·048 | 26 | .. | .. | 3·7 |
| Calcium | Ca | 40·1 | 25·5 | 1·57 | 0·170 | 780 | .. | .. | 22·1 |
| Cerium | Ce | 140·2 | 21·0 | 6·68 | 0·045 | 623 | .. | .. | .. |
| Chromium | Cr | 52·0 | 7·7 | 6·80 | 0·120 | 1482 | .. | .. | .. |
| Cobalt | Co | 59·0 | 6·9 | 8·50 | 0·103 | 1464 | 0·0000123 | .. | 15·6 |
| Columbium | Cb | 93·5 | 7·4 | 12·70 | 0·071 | .. | .. | .. | .. |
| Copper | Cu | 63·6 | 7·1 | 8·93 | 0·093 | 1084 | 0·0000167 | 0·924 | 94·0 |
| Gallium | Ga | 69 9 | 11·8 | 5·90 | 0·079 | 30 | .. | .. | .. |
| Glucinum | Gl | 9 1 | 4·7 | 1·93 | 0·621 | .. | .. | .. | .. |
| Gold | Au | 197·2 | 10·2 | 19·32 | 0·031 | 1065 | 0·0000144 | 0·700 | 66·8 |
| Indium | In | 114·8 | 15·5 | 7·42 | 0·057 | 155 | 0·0000417 | .. | 16·5 |
| Iridium | Ir | 193·1 | 8·6 | 22·42 | 0·033 | 1950 | 0·0000070 | .. | .. |
| Iron | Fe | 55·8 | 7·1 | 7·86 | 0·110 | 1505 | 0·0000121 | 0·147 | 16·2 |
| Lanthanum | La | 139·0 | 22·4 | 6·20 | 0·045 | 810 | .. | .. | .. |
| Lead | Pb | 207·1 | 18·2 | 11·37 | 0·031 | 327 | 0·0000292 | 0·084 | 7·2 |
| Lithium | Li | 6·9 | 13·0 | 0·54 | 0·941 | 186 | .. | .. | 17·5 |
| Magnesium | Mg | 24·3 | 14·0 | 1·74 | 0·250 | 633 | 0·0000269 | 0·343 | 33·7 |
| Manganese | Mn | 54·9 | 6·9 | 8·00 | 0·120 | 1207 | .. | .. | .. |
| Mercury | Hg | 200·6 | 14·7 | 13·59 | 0·032 | −39 | 0·0000610 | 0·020 | 1·6 |
| Molybdenum | Mo | 96·0 | 11·2 | 8·60 | 0·072 | 2500 | .. | .. | .. |
| Nickel | Ni | 58·7 | 6·7 | 8·80 | 0·108 | 1427 | 0·0000127 | 0·141 | 21·2 |
| Osmium | Os | 190 9 | 8·5 | 22·48 | 0·031 | 2500 | 0·0000065 | .. | 15·5 |
| Palladium | Pd | 106·7 | 9·3 | 11·50 | 0·059 | 1535 | 0·0000117 | 0·168 | 14 5 |
| Platinum | Pt | 195·2 | 9·1 | 21·50 | 0·032 | 1710 | 0·0000089 | 0·166 | 13·4 |
| Potassium | K | 39·1 | 45·5 | 0·86 | 0·170 | 62 | 0·0000841 | .. | 20·8 |
| Rhodium | Rh | 102·9 | 8·5 | 12·10 | 0·058 | 1660 | 0·0000085 | .. | .. |
| Rubidium | Rb | 85·5 | 55·9 | 1·53 | 0·077 | 38 | .. | .. | .. |
| Ruthenium | Ru | 101·7 | 8·3 | 12·26 | 0·061 | 1800 | 0·0000096 | .. | .. |
| Silver | Ag | 107·9 | 10·2 | 10·53 | 0·056 | 961 | 0·0000192 | 0·993 | 100·0 |
| Sodium | Na | 23·0 | 23·8 | 0·97 | 0·290 | 95 | 0·0000710 | 0·365 | 37·3 |
| Strontium | Sr | 87·6 | 34·5 | 2·54 | .. | 800 | .. | .. | 6·7 |
| Tantalum | Ta | 181·5 | 16·7 | 10·80 | 0·036 | 2910 | 0·0000079 | .. | 8·9 |
| Tellurium | Te | 127·5 | 20·4 | 6·25 | 0·049 | 440 | 0·0000167 | .. | 6·8 |
| Thallium | Tl | 204·0 | 17·2 | 11·85 | 0·033 | 303 | 0·0000302 | .. | 8·3 |
| Thorium | Th | 232·4 | 20·9 | 11·10 | 0·028 | .. | .. | .. | .. |
| Tin | Sn | 119·0 | 16·3 | 7·29 | 0·055 | 232 | 0·0000223 | 0·155 | 11·3 |
| Titanium | Ti | 48·1 | 9·9 | 4·87 | 0·130 | .. | .. | .. | .. |
| Tungsten | W | 184·0 | 9·6 | 19·10 | 0·034 | 3100 | .. | .. | 1·7 |
| Uranium | U | 238·5 | 12·8 | 18·70 | 0·028 | .. | .. | .. | .. |
| Vanadium | V | 51·0 | 9·3 | 5·50 | 0·125 | 1680 | .. | .. | .. |
| Yttrium | Yt | 89·0 | 23·4 | 3·80 | .. | .. | .. | .. | .. |
| Zinc | Zn | 65·4 | 9·1 | 7·15 | 0·094 | 419 | 0·0000291 | 0·269 | 25·2 |
| Zirconium | Zr | 90·6 | 21·8 | 4·15 | 0·066 | 1500 | .. | .. | .. |

# MELTING POINTS OF THE CHEMICAL ELEMENTS

Bureau of Standards

| Element | F | C | Element | F | C |
|---|---|---|---|---|---|
| Helium | < −456 | < −271 | Praseodymium | 1725 | 940? |
| Hydrogen | −434 | −259 | Germanium | 1756 | 958 |
| Neon | −423 | −253? | SILVER | 1761 | 960.5 |
| Fluorine | −369 | −223 | Glucinum | ........... | >Ag |
| Oxygen | −360 | −218 | Radium | ........... | ? |
| Nitrogen | −346 | −210 | GOLD | 1945.5 | 1063.0 |
| Argon | −306 | −188 | COPPER | 1981.5 | 1083.0 |
| Krypton | −272 | −169 | Manganese | 2237 | 1225 |
| Xenon | −220 | −140 | Yttrium | ........... | ? |
| Chlorine | −150.5 | −101.5 | Samarium | 2370–2550 | 1300–1400 |
| MERCURY | − 37.7 | − 38.7 | | | |
| Bromine | + 18.9 | − 7.3 | Scandium | ........... | ? |
| Cæsium | 79 | 26 | Silicon | 2588 | 1420 |
| Gallium | 86 | 30 | NICKEL | 2646 | 1452 |
| Rubidium | 100 | 38 | Cobalt | 2714 | 1490 |
| Phosphorus | 111.4 | 44 | Chromium | 2750 | 1510 |
| Potassium | 144 | 62.3 | IRON | 2768 | 1520 |
| Sodium | 207.5 | 97.5 | PALLADIUM | 2820 | 1549 |
| Iodine | 236.5 | 113.5 | Zirconium | 3100 | 1700? |
| Sulphur $S_{I}$ | 235.0 | 112.8 | Thorium | >3090 | >1700 |
| Sulphur $S_{II}$ | 246.6 | 119.2 | | <Pt. | <Pt. |
| Sulphur $S_{III}$ | 244.2 | 106.8 | Vanadium | 3150 | 1730? |
| Indium | 311 | 155 | PLATINUM | 3191 | 1755 |
| Lithium | 367 | 186 | Beryllium | >3270 | >1800? |
| Selenium | 422–428 | 217–220 | Ytterbium | ........... | ? |
| TIN | 449.4 | 231.9 | Titanium | 3450 | 1900? |
| Bismuth | 520 | 271 | Rhodium | 3525 | 1940 |
| Thallium | 576 | 302 | Ruthenium | >3550 | >1950 |
| CADMIUM | 609.6 | 320.9 | Columbium | | |
| LEAD | 621.1 | 327.4 | (Niobium) | 4000 | 2200? |
| ZINC | 786.9 | 419.4 | Boron | 4000–4500 | 2200–2500 |
| Tellurium | 846 | 452 | | | |
| ANTIMONY | 1166 | 630.0 | Iridium | 4170 | 2300? |
| Cerium | 1184 | 640 | Uranium | ........... | ? |
| Magnesium | 1204 | 651 | Molybdenum | 4500 | 2500? |
| ALUMINIUM | 1217.7 | 658.7 | Osmium | 4900 | 2700? |
| Calcium | 1490 | 810 | Tantalum | 5160 | 2850 |
| Lanthanum | 1490 | 810? | TUNGSTEN | 5430 | 3000 |
| Strontium | ........... | >Ca<Ba? | Carbon | >6500 for p = 1 At. | >3600 for p = 1 At. |
| Neodymium | 1544 | 840? | | | |
| Arsenic | 1560 | 850? | | | |
| Barium | 1560 | 850 | | | |

The values of the melting points used by the Bureau of Standards as standard temperatures for the calibration of thermometers and pyrometers are indicated in capitals. The other values have been assigned after a careful survey of all the available data.

As nearly as may be, all values, in particular the standard points, have been reduced to a common scale, the thermodynamic scale. For high temperatures, and for use with optical pyrometers, this scale is satisfied very exactly by taking $c_2 = 14{,}500$ in the formula for Wien's law connecting I, monochromatic luminous intensity of wave length $\lambda$, and T, absolute temperature: $\log I/I. = c_1 \lambda \log e \; (1/T_2 - 1/T)$. For all purposes, except the most accurate investigations, the thermodynamic scale is identical with any of the gas scales.

## Weight and Specific Gravity of Metals

| Metal | Specific Gravity | Weight Cu. In. | Weight Cu. Ft. | Metal | Specific Gravity | Weight Cu. In. | Weight Cu. Ft. |
|---|---|---|---|---|---|---|---|
| Aluminum | 2.56 to 2.80 | .097 | 167 | Lithium | 0.59 | .021 | 37 |
| Antimony | 6.70 to 6.72 | .242 | 418 | Magnesium | 1.69 to 1.75 | .062 | 107 |
| Barium | 3.75 to 4.00 | .140 | 242 | Manganese | 6.86 to 8.03 | .269 | 465 |
| Bismuth | 9.70 to 9.90 | .354 | 612 | Mercury | 13.596 | .491 | 848 |
| Cadmium | 8.54 to 8.67 | .311 | 537 | Molybdenum | 8.40 to 8.60 | .307 | 530 |
| Cæsium | 1.88 to 1.90 | .068 | 118 | Nickel | 8.9 to 9.2 | .327 | 565 |
| Calcium | 1.58 | .057 | 99 | Osmium | 21.40 to 22.40 | .791 | 1,366 |
| Cerium | 6.62 to 6.72 | .241 | 416 | Palladium | 11.0 to 12.0 | .416 | 718 |
| Chromium | 6.52 to 6.73 | .239 | 414 | Platinum | 21.20 to 21.70 | .774 | 1,338 |
| Cobalt | 8.50 to 9.10 | .318 | 549 | Potassium | 0.85 to 0.88 | .031 | 54 |
| Columbium | 7.10 to 7.40 | .262 | 452 | Rhodium | 11.00 to 12.10 | .417 | 721 |
| Copper | 8.80 to 8.95 | .321 | 554 | Ruthenium | 11.00 to 11.40 | .405 | 699 |
| Didymium | 6.54 | .236 | 408 | Silver | 10.40 to 10.57 | .378 | 654 |
| Gallium | 5.93 | .214 | 370 | Sodium | 0.97 to 0.99 | .035 | 61 |
| Germanium | 5.46 | .197 | 341 | Strontium | 2.50 to 2.58 | .091 | 158 |
| Glucinium | 1.86 to 2.06 | .071 | 122 | Thallium | 11.8 to 11.9 | .428 | 739 |
| Gold | 19.26 to 19.34 | .697 | 1,204 | Tin | 7.29 to 7.30 | .263 | 455 |
| Indium | 7.27 to 7.42 | .266 | 459 | Titanium | 5.30 | .192 | 331 |
| Iridium | 21.78 to 22.42 | .798 | 1,379 | Thorium | 9.4 to 10.1 | .352 | 608 |
| Iron, cast | 7.21 | .260 | 450 | Tungsten | 19.12 | .690 | 1,193 |
| Iron, wrought | 7.77 | .280 | 485 | Uranium | 18.33 to 18.65 | .668 | 1,154 |
| Iron (steel) | 7.8 to 7.9 | .284 | 490 | Zinc, cast | 7.04 to 7.16 | .256 | 443 |
| Lanthanum | 6.05 to 6.16 | .220 | 381 | Zinc, wrought | 7.19 | .260 | 449 |
| Lead | 11.34 to 11.36 | .410 | 708 | Zirconium | 4.14 | .149 | 258 |

## Weight and Specific Gravity of Various Substances

| Substance | Specific Gravity | Weight Cu. In. | Weight Cu. Ft. | Substance | Specific Gravity | Weight Cu. In. | Weight Cu. Ft. |
|---|---|---|---|---|---|---|---|
| Alabaster | 2.76 | .100 | 172 | Clay | 1.92 | .069 | 120 |
| Alum | 1.72 | .062 | 107 | Concrete, stone | 2.26 | .082 | 141 |
| Asphaltum | 1.31 | .042 | 82 | Concrete, cinder | 1.60 | .058 | 100 |
| Barytes | 4.50 | .163 | 281 | Concrete, slag | 2.10 | .076 | 131 |
| Basalt | 2.90 | .105 | 181 | Copper ore | 4.20 | .152 | 262 |
| Bauxite | 2.55 | .092 | 159 | Dolomite | 2.90 | .105 | 181 |
| Bluestone | 2.20 | .079 | 137 | Earth, argillaceous | 1.60 | .058 | 100 |
| Borax | 1.75 | .063 | 109 | Earth, light vege | 1.40 | .050 | 87 |
| Brick | 1.90 | .069 | 119 | Earth, potters' | 1.90 | .069 | 119 |
| Chalk, air-dried | 2.51 | .091 | 157 | Feldspar | 2.55 | .092 | 159 |

WEIGHT AND SPECIFIC GRAVITY OF VARIOUS SUBSTANCES—(*Cont.*)

| Substance | Specific Gravity | Weight | | Substance | Specific Gravity | Weight | |
|---|---|---|---|---|---|---|---|
| | | Cu. In. | Cu. Ft. | | | Cu. In. | Cu. Ft. |
| Flint | 2.63 | .095 | 164 | Phosphate rock | 3.20 | .116 | 200 |
| Glass, common | 2.50 | .090 | 156 | Phosphorus | 1.80 | .065 | 112 |
| Glass, flint | 2.60 | .094 | 162 | Pitch | 1.09 | .039 | 68 |
| Granite, gneiss | 2.66 | .096 | 166 | Porcelain | 2.31 | .083 | 144 |
| Granite, gray | 2.93 | .106 | 183 | Porphyry | 2.75 | .100 | 172 |
| Graphite | 2.20 | .079 | 137 | Portland cmt., loose | 1.38 | .050 | 86 |
| Gravel, loose | .... | .056 | 95 | Portland cmt., set | 2.90 | .105 | 181 |
| Gravel, packed | .... | .064 | 110 | Potash | 2.18 | .079 | 136 |
| Greenstone | 3.00 | .108 | 187 | Pumice | .64 | .023 | 40 |
| Gypsum | 2.00 | .072 | 125 | Quartz | 2.66 | .096 | 166 |
| Hornblende | 3.00 | .108 | 187 | Rock crystal | 2.65 | .095 | 165 |
| Ice, melting | .90 | .032 | 56 | Salt, common solid | 1.92 | .069 | 120 |
| Iron ore, hematite | 5.20 | .187 | 324 | Salt rock | 2.30 | .083 | 144 |
| Iron ore, limonite | 3.80 | .137 | 237 | Sand, dry, loose | .... | .057 | 98 |
| Iron ore, magnetic | 5.09 | .184 | 318 | Sand, packed | .... | .064 | 110 |
| Iron slag | 2.75 | .100 | 172 | Sand, wet | .... | .068 | 118 |
| Lava | 2.26 | .082 | 141 | Sandstone | 2.30 | .083 | 144 |
| Lead ore | 7.45 | .269 | 465 | Schist, rough | 2.30 | .083 | 144 |
| Lime, loose | 2.75 | .100 | 172 | Schist, slate | 2.80 | .101 | 175 |
| Limestone carboniferous | 2.69 | .097 | 168 | Serpentine | 2.60 | .094 | 162 |
| Limestone, magnesian | 2.86 | .103 | 178 | Shale, slate | 2.80 | .101 | 175 |
| Limestone, marble | 2.65 | .095 | 165 | Slate | 2.73 | .098 | 170 |
| Manganese ore | 4.15 | .150 | 259 | Snow, loose | .... | .... | 10 |
| Magnesite | 3.00 | .108 | 187 | Snow, compact | .... | .... | 50 |
| Marble | 2.70 | .097 | 168 | Soapstone, talc | 2.70 | .097 | 168 |
| Marl | 1.75 | .063 | 109 | Sulphur | 2.00 | .072 | 125 |
| Mica | 2.75 | .100 | 172 | Talc, steatite | 2.70 | .097 | 168 |
| Mortar | 1.65 | .060 | 103 | Tar, bituminous | 1.20 | .043 | 75 |
| Mud | 1.63 | .059 | 102 | Tile | 1.90 | .069 | 119 |
| Paraffine | .89 | .032 | 56 | Tin ore | 6.70 | .242 | 418 |
| Peat, dense | .76 | .027 | 47 | Trap | 2.72 | .098 | 170 |
| Peat, fibrous | .46 | .017 | 29 | Zinc ore | 4.05 | .146 | 253 |

WEIGHT AND SPECIFIC GRAVITY OF AMERICAN COALS

| | Specific Gravity | Pounds per Cubic Foot |
|---|---|---|
| Anthracite, Lehigh Co., Pa | 1.57 | 98 |
| Anthracite, Carbon Co., Pa | 1.36 | 85 |
| Semi-Anthracite, Wilkesbarre, Pa | 1.40 | 87 |
| Semi-Bituminous, Cumberland, Md | 1.41 | 88 |

WEIGHT AND SPECIFIC GRAVITY OF AMERICAN COALS—(*Cont.*)

| | Specific Gravity | Pounds per Cubic Foot |
|---|---|---|
| Semi-Bituminous, Blossburg, Pa | 1.32 | 82 |
| Bituminous, Pennsylvania | 1.35 | 84 |
| Block Coal, Indiana | 1.29 | 80 |
| Brown Coal, Kentucky | 1.17 | 73 |
| Caking Coal, short flame | 1.33 | 83 |
| Caking Coal, long flame | 1.30 | 81 |
| Caking Coal, gas | 1.29 | 80 |
| Cannel Coal, Indiana | 1.23 | 77 |
| Coke, Connellsville | 1.28 | 80 |
| Coke, loose per cubic foot | .... | 50 |
| Lignite, Kentucky | 1.20 | 75 |
| Lignite, Texas | 1.23 | 77 |
| Lignite, Colorado | 1.28 | 80 |
| Peat, light fibrous | .... | 20 |
| Peat, dense | .... | 41 |
| Peat, compressed, hard | .... | 75 |

WEIGHT AND SPECIFIC GRAVITY OF VARIOUS KINDS OF WOOD

| Wood | Specific Gravity | Weight Cubic Inch | Weight Cubic Foot | Wood | Specific Gravity | Weight Cubic Inch | Weight Cubic Foot |
|---|---|---|---|---|---|---|---|
| Apple | .75 | .027 | 47 | Mahogany, Hond. | .56 | .020 | 35 |
| Ash | .74 | .027 | 46 | Mahogany, Spa. | .85 | .031 | 53 |
| Basswood | .46 | .017 | 29 | Maple | .69 | .025 | 43 |
| Beech | .80 | .029 | 50 | Oak, red | .64 | .023 | 40 |
| Birch | .64 | .023 | 40 | Oak, live | .95 | .034 | 59 |
| Butternut | .38 | .014 | 24 | Oak, white | .74 | .027 | 46 |
| Cedar | .51 | .019 | 32 | Pine, loblolly | .62 | .023 | 39 |
| Cherry | .78 | .028 | 49 | Pine, long leaf | .75 | .027 | 47 |
| Chestnut | .66 | .024 | 41 | Pine, Norway | .61 | .022 | 38 |
| Cork | .24 | .009 | 15 | Pine, Oregon | .54 | .020 | 34 |
| Cypress | .48 | .017 | 30 | Pine, pitch | .83 | .030 | 52 |
| Ebony | 1.21 | .044 | 76 | Pine, red | .48 | .017 | 30 |
| Elm | .58 | .021 | 36 | Pine, white | .42 | .015 | 26 |
| Fir, Douglas | .54 | .020 | 34 | Pine, yellow | .48 | .017 | 30 |
| Gum, blue | .83 | .030 | 52 | Poplar | .48 | .017 | 30 |
| Gum, red | .51 | .019 | 32 | Redwood, Cal. | .42 | .015 | 26 |
| Gum, water | .99 | .036 | 62 | Spruce | .51 | .019 | 32 |
| Hemlock | .53 | .019 | 33 | Sycamore | .50 | .018 | 31 |
| Hickory | .75 | .027 | 47 | Tamarack | .72 | .026 | 45 |
| Larch | .53 | .019 | 33 | Teak, Indian | .77 | .028 | 48 |
| Lignum vitæ | 1.25 | .045 | 78 | Teak, African | .98 | .035 | 61 |
| Linden | .46 | .017 | 29 | Walnut | .67 | .024 | 42 |
| Locust | .71 | .025 | 44 | Willow | .50 | .018 | 31 |

NOTE. Weights are approximate only. Green timber may have as much as 50% moisture. Well-seasoned, air-dried timber may have 15 to 20% moisture.

# SPECIFIC GRAVITY OF LIQUIDS AND GASES

## Weight and Specific Gravity of Various Liquids

| Liquid | Sp. Gr. | Weight U. S. Gal. | Weight Cu. In. | Weight Cu. Ft. | Liquid | Sp. Gr. | Weight U. S. Gal. | Weight Cu. In. | Weight Cu. Ft. |
|---|---|---|---|---|---|---|---|---|---|
| Acetone | 0.792 | 6.55 | .028 | 49 | Oil, castor | .969 | 8.02 | .035 | 60 |
| Acid, hydrochloric | 1.207 | 10.03 | .043 | 75 | Oil, cocoanut | .925 | 7.75 | .034 | 58 |
| Acid, nitric | 1.519 | 12.70 | .055 | 95 | Oil, cottonseed | .926 | 7.75 | .034 | 58 |
| Acid, sulphuric | 1.800 | 14.97 | .065 | 112 | Oil, creosote | 1.070 | 8.96 | .039 | 67 |
| Alcohol, amyl | .811 | 6.82 | .030 | 51 | Oil, lard | .920 | 7.62 | .033 | 57 |
| Alcohol, butyl | .802 | 6.68 | .029 | 50 | Oil, linseed | .942 | 7.89 | .034 | 59 |
| Alcohol, ethyl | .793 | 6.55 | .028 | 49 | Oil, mineral (lub.) | .913 | 7.62 | .033 | 57 |
| Alcohol, methyl | .792 | 6.55 | .028 | 49 | Oil, olive | .918 | 7.62 | .033 | 57 |
| Alcohol, octyl | .830 | 6.95 | .030 | 52 | Oil, palm | .905 | 7.49 | .032 | 56 |
| Alcohol, propyl | .808 | 6.68 | .029 | 50 | Oil, pine | .855 | 7.09 | .031 | 53 |
| Benzine | .899 | 7.49 | .032 | 56 | Oil, poppy | .924 | 7.75 | .034 | 58 |
| Bromine | 3.187 | 26.60 | .115 | 199 | Oil, rapeseed | .914 | 7.62 | .033 | 57 |
| Carbolic acid | .960 | 8.02 | .035 | 60 | Oil, resin | .955 | 8.02 | .035 | 60 |
| Carbon disulphide | 1.293 | 10.86 | .047 | 81 | Oil, whale | .920 | 7.62 | .033 | 57 |
| Chloroform | 1.480 | 12.30 | .053 | 92 | Oil, turpentine | .873 | 7.22 | .031 | 54 |
| Ether | .736 | 6.15 | .027 | 46 | Oil, petroleum | .878 | 7.35 | .032 | 55 |
| Glycerine | 1.260 | 10.56 | .046 | 79 | Oil, petr. (light) | .800 | 6.68 | .029 | 50 |
| Naphtha (wood) | .840 | 6.95 | .030 | 52 | Pyroligneous acid | .800 | 6.68 | .029 | 50 |
| Naphtha (petroleum) | .665 | 5.48 | .024 | 41 | Sea water | 1.025 | 8.56 | .037 | 64.3 |
| Nitroglycol | 1.495 | 12.43 | .054 | 93 | Soda lye | 1.210 | 10.16 | .044 | 76 |
| Nitroglycerin | 1.600 | 13.37 | .058 | 100 | Toluene | .858 | 7.22 | .031 | 54 |
| Oil, anise-seed | .996 | 8.34 | .036 | 62 | Water, pure | 1.000 | 8.34 | .036 | 62.4 |

## Weight and Specific Gravity of Various Gases

| Gases | Sp. Gr. | Weight Cu. Ft. | Weight Cu. Ft. per Lb. | Gases | Sp. Gr. | Weight Cu. Ft. | Weight Cu. Ft. per Lb. |
|---|---|---|---|---|---|---|---|
| Air (32° F.) | 1.000 | .0807 | 12.387 | Gas, natural | .475 | .0383 | 26.110 |
| Acetylene, $C_2H_2$ | .898 | .0724 | 13.812 | Hydrogen | .069 | .0056 | 178.571 |
| Ammonia, $NH_3$ | .592 | .0478 | 20.921 | Marsh gas, CH | .559 | .0451 | 22.173 |
| Carbon dioxide, $CO_2$ | 1.529 | .1234 | 8.104 | Nitrogen | .971 | .0784 | 12.755 |
| Carbon monoxide, CO | .967 | .0780 | 12.821 | Nitric oxide, NO | 1.039 | .0838 | 11.933 |
| Chlorine, $Cl_2O$ | 2.422 | .1955 | 5.115 | Nitrous oxide, $N_2O$ | 1.527 | .1232 | 8.117 |
| Ethylene, $C_2H_4$ | .967 | .0780 | 12.821 | Oxygen | 1.106 | .0893 | 11.198 |
| Gas, illuminating | .400 | .0323 | 30.960 | Sulphur dioxide, $SO_2$ | 2.247 | .1813 | 5.516 |

## HORSEPOWER

### BUREAU OF STANDARDS

James Watt, the inventor of the modern steam engine, adopted the term "horsepower" as a unit for expressing the power of his steam engines, and defined its value in gravitational units, viz., foot-pounds per minute. The value was derived from experiments made about the year 1775.

Some heavy horses of Barclay & Perkins's brewery, London, were caused to raise a weight from the bottom of a deep well by pulling horizontally on a rope passing over a pulley. It was found that a horse could raise a weight of 100 pounds while walking at the rate of 2.5 miles per hour. This is equivalent to 22,000 foot-pounds per minute. Watt added 50 per cent to this value, giving 33,000 foot-pounds per minute, or 550 foot-pounds per second. The addition of 50 per cent was an allowance made for friction, so that a purchaser of one of his engines might have no ground for complaint. The figure thus arrived at by Watt is admitted to be in excess of the power of an average horse for continuous work, and is probably at least twice the power of the average horse working six hours per day.

Since the time of Watt, his value has been in general use in England and the United States, and 550 foot-pounds per second is known as the English horsepower.

**The Pound as a Unit of Force** has generally been used as a "gravitational" unit, the characteristic of the gravitational units being that their magnitudes vary with locality as $g$ varies. Thus, a pound force is equal to the force of gravity on a pound mass at any place where measurements happen to be made. The one advantage of the gravitational system is that a given mass exerts the same number of pounds of force no matter what its location. But by this mode of definition the magnitude of the pound force is not constant, as it varies with $g$. A few writers, on the other hand, have defined the pound force as a fixed unit, taking it as equal to the force of gravity on a pound mass at some one particular place—e. g., Paris, or 45° latitude and sea level—thus destroying the gravitational character of the unit.

The unit of force can be made definite and fixed, however, without abolishing the gravitational system. This is done by recognizing the difference between the absolute and the gravitational pound by the use of the terms "standard" and "local," respectively. The principle involved is that contained in the definition of "standard weight" by the International Conference on Weights and Measures in 1901. The statement by the conference is given herewith:

The term weight designates a quantity of the same nature as a force; the weight of a body is the product of the mass of that body, by the acceleration of gravity; in particular, the standard weight of a body is the product of the mass of that body by the standard acceleration of gravity.

The number adopted in the International Service of Weights and Measures for the value of the standard acceleration of gravity is 980.665 centimeters per second (*Procès-Verbaux des Séances, Comité International des Poids et Mesures*, p. 172, 1901).

By analogy with "standard weight," the "standard pound force" may be defined as equal to the force of gravity on a pound mass at a place where $g$ has the standard value, 980.665 centimeters per second per second or 32.1740 feet per second per second. Likewise the "local pound force" in any given locality may be defined as equal to the force of gravity on a pound mass in that given locality.

**The Standard Value of g,** 980.665 centimeters per second per second, was originally intended to represent the latitude of 45° and sea level. It has been widely used as a standard value for barometric reductions, etc., since 1901, and there is no reason why it should not continue in use as a standard value, although the accepted theoretical value for 45° and sea level is now a few parts in 100,000 different. The value, 980.665, is the result of a calculation made by the International Committee on Weights and Measures (*Procès-Verbaux des Séances*, p. 165, 1901) from Defforges' absolute determination (*Ibid.*, p. 181, 1891; *Mémorial du Dépôt Général de la Guerre* 15, (1), 1894) of $g$ at the International Bureau in 1888.

In calculating the equivalent of the horsepower in various units for different latitudes, the following formula is used: $g = 978.038\,(1 + 0.005302 \sin^2 \phi - 0.000007 \sin^2 2\phi)$,

where $\phi$ is the latitude. This formula is accepted by the United States Coast and Geodetic Survey, and is the result of observations all over the United States with Hayford's corrections for "isostatic compensation." It is referred to the absolute determination of $g$ at Potsdam about 1900.

TABLE 1

VARIOUS VALUES ADOPTED FOR THE HORSEPOWER

[Foot-pounds given in terms of the local foot and pound]

| | Foot-Pounds per Second | English Horse-power | Kilogram-meters per Second | Authority* |
|---|---|---|---|---|
| England and United States | 550. | 1.0000 | 76.041 | V |
| Austria (old) | 430. | 1.0010 | 76.119 | H |
| Switzerland | 500. | 0.9863 | 75.000 | A |
| Sweden | 600. | 0.9856 | 74.943 | N |
| Russia | 550. | 1.0000 | 76.041 | N |
| Prussia | 480. | 0.9906 | 75.325 | H |
| Saxony | 530. | 0.9869 | 75.045 | H |
| Baden | 500. | 0.9863 | 75.000 | H |
| Würtemburg | 525. | 0.9890 | 75.204 | H |
| Bavaria | 460. | 0.9888 | 75.190 | K |
| Modern Germany, Austria, France, Italy, etc. | ........ | 0.9863 | 75.000 | V |

*V = various. H = Des Ingenieurs Taschenbuch-Hütte II (Berlin, 1902). A = F. Autenheimer, Mechanische Arbeit (Stuttgart, 1871), p. 15. N = J. W. Nystrom, Elements of Mechanics (Philadelphia, 1875), p. 63. K = Karnarsch und Heeren's Technisches Wörterbuch VI (1883), p. 637; and Alexander's Weights and Measures (Baltimore, 1850).

After the metric system had come into use in France, Germany and Austria the values of the horsepower in the various countries were reduced to kilogrammeters per second, with the results shown in the table. The values range from 75 to 76 kilogrammeters per second, averaging only a little more than 75. Hence, this round value, 75, has been adopted generally on the Continent as the value of the horsepower.

The English value, 550 foot-pounds per second, is, however, equivalent to 76.041 kilogrammeters per second, and hence it is that there is a difference of nearly 1.5 per cent between the value generally used in English and American practice and that used in continental practice. Reduced to watts, the English horsepower is generally taken as 746 watts, although the precise equivalent, in watts, of 550 foot-pounds per second depends on the acceleration of gravity, and hence on the latitude and altitude.

TABLE 2

VALUE OF THE ENGLISH AND AMERICAN HORSEPOWER (746 WATTS) IN LOCAL FOOT-POUNDS PER SECOND AT VARIOUS LATITUDES AND ALTITUDES

| Altitude | Latitude | | | | |
|---|---|---|---|---|---|
| | 0° (Equator) | 30° | 45° | 60° | 90° (Pole) |
| Sea level | 551.70 | 550.97 | 550.24 | 549.52 | 548.79 |
| 5000 feet | 551.86 | 551.13 | 550.41 | 549.68 | 548.95 |
| 10,000 feet | 552.03 | 551.30 | 550.57 | 549.85 | 549.12 |

The foregoing table may be put in the following approximate form for ease of remembering.

TABLE 3

ENGLISH AND AMERICAN HORSEPOWER (746 WATTS) AT VARIOUS LATITUDES

| Latitude | Local Foot-Pounds per Second (Approx.) |
|---|---|
| 90°, pole | 549 |
| 50°, London | 550 |
| (39°, Washington) | (550.5) |
| 30°, New Orleans | 551 |
| 0°, equator | 552 |

The value of the English horsepower may also be given in metric units for various latitudes and altitudes, as follows:

TABLE 4

VALUE OF THE ENGLISH AND AMERICAN HORSEPOWER (746 WATTS) IN LOCAL KILOGRAMMETERS PER SECOND AT VARIOUS LATITUDES AND ALTITUDES

| Altitude | LATITUDE | | | | |
|---|---|---|---|---|---|
| | 0° Equator | 30° | 45° | 60° | 90° (Pole) |
| Sea level | 76.275 | 76.175 | 76.074 | 75.973 | 75.873 |
| 1500 meters (= 5000 feet approximately) | 76.297 | 76.197 | 76.096 | 75.995 | 75.895 |
| 3000 meters (= 10,000 feet approximately) | 76.320 | 76.220 | 76.119 | 76.018 | 75.918 |

By interpolation one can take out of these tables the proper value of the horsepower in gravitation measure (either foot-pounds or kilogrammeters per second) for any latitude and altitude.

**Continental Horsepower.**—It is unfortunate that the value of the horsepower on the Continent of Europe was not taken as 76 kilogrammeters per second instead of 75, in order that it might agree with the English value, as was originally intended. It is perhaps unlikely that a change of 76 could now be made, or that an agreement could be reached by which the continental and the English horsepower would correspond to the same number of watts. It is to some extent customary for continental writers to distinguish the two horsepowers by the words "English" and "metric." The Bureau calls the latter the "continental horsepower."

German writers speak of the "Englische Pferdestärke" and the "metrische Pferdestärke." The term "Pferdestärke" is now the preferred name for the horsepower in Germany, the old term "Pferdekraft" being unsuitable because "Kraft" means "force."

In France, the old term "force-de-cheval" has been given up for "cheval-vapeur."

**Poncelet.**—There is another unit of power which has been used in Europe, the "poncelet," or 100 kilogrammeters per second. This unit was named in honor of Jean Victor Poncelet, who introduced the teaching of kinematics at the Sorbonne in 1838. This unit was adopted in France shortly before 1846. It was adopted as a unit of power in 1889 by the "Congrès international de mécanique appliquée." Its use is still permitted in the electrical regulations issued by the "Association alsacienne des Propriétaires d'Appareils à Vapeur." It has not, however, been much used in practice. This is probably due in part to the fact that the horsepower had so firm a hold as the unit of power, and in part to the very near equivalence of the poncelet to the kilowatt. The poncelet is open to the same objection as the horsepower when the latter is rigidly defined as a certain number of foot-pounds or kilogrammeters per second, viz., that the power it represents varies from place to place.

**Equivalents of the Continental Horsepower.**—The continental horsepower is generally given either as 75 kilogrammeters per second or as 736 watts. These two equivalents are independent definitions and are likely to cause confusion unless one of them is assigned to some definite place on the earth's surface. The unit, to be definite, should represent the same rate of work at all places. The continental horsepower, then, should be taken as 736 watts, which is equivalent to 75 local kilogrammeters per second at latitude 52° 30′, or Berlin. The number of kilogrammeters per second expressing this amount of power will be smaller than 75 at more northern latitudes and larger at lower latitudes. The values at various latitudes at sea level are given in Table 5:

TABLE 5

Continental Horsepower (736 Watts) in Local Kilogrammeters per Second

| Altitude | Latitude | | | | |
|---|---|---|---|---|---|
| | 0° Equator | 30° | 45° | 60° | 90° (Pole) |
| Sea level | 75.253 | 75.153 | 75.054 | 74.955 | 74.856 |
| 1500 meters | 75.275 | 75.175 | 75.076 | 74.977 | 74.878 |
| 3000 meters | 75.297 | 75.197 | 75.098 | 74.999 | 74.900 |

**Horsepower an Unsuitable Unit.**—On account of the variation with $g$, and because the equivalents of the horsepower are not decimal multiples of any of the fundamental units, and, further, because its definition and value are different on the Continent of Europe from its definition and value in England and America, it has long been felt that the horsepower is an unsuitable unit for many purposes. Modern engineering practice is constantly tending away from the horsepower and toward the watt and kilowatt. In Germany, it has been proposed to call the kilowatt "Neupferd" (new horsepower), to make its use appeal more strongly to those who have become firmly attached to the horsepower. The objection to the horsepower has been particularly strong in electrical engineering. The International Congress of Electricians at Paris, in 1889, recommended that the power of machines be expressed in kilowatts instead of in horsepower. A more definite and powerful action with a view to the elimination of the horsepower was taken by the International Electro-technical Commission at Turin, Italy, in 1911. This body, composed of the representatives of great electrical interests all over the world, recommended that in all countries electrical machinery, including motors, be rated in kilowatts only.

**Kilowatt as the Unit of Power.**—It is considered desirable that the watt and kilowatt be used as the units of power, whenever possible, for all kinds of scientific, engineering, and other work. It is not unlikely that the unit of horsepower will ultimately go out of use. In the meantime, however, it is desirable that its definition be uniform. If the horsepower is to represent the same amount of power at different places, its relation to the watt must be a constant number, and the number of local foot-pounds or kilogrammeters per second which it represents must vary from place to place. Table 2 and others of this circular show clearly this variation with locality.

It might be feared that some confusion could arise because of the independent definitions of the mechanical watt and the "international" electrical watt. The watt and kilowatt are defined primarily in purely mechanical terms, and not electrically at all. That they have been used mainly in electrotechnical work is merely accidental, and is due to the fact that they are metric units and so fit in naturally with the metric units in which all electrical quantities are universally expressed. Any kind of power may properly be measured in kilowatts. For example, in the case of the hydraulic power furnished by a flowing stream, the power is given in kilowatts by multiplying 0.163 into the product of the head in meters by the flow in cubic meters per minute; the power is likewise given in kilowatts by multiplying 0.000188 into the product of the head in feet by the flow in gallons per minute. The watt is defined directly in terms of the fundamental units of mass, length, and time, in the "meter-kilogram-second" system, thus: "The watt is the power developed by the action, with a velocity of 1 meter per second, of a force capable of giving to a mass of 1 kilogram in one second a velocity

of 1 meter per second." The "international watt," however, is defined in terms of concrete electrical standards, which electrical standards represent practically, as nearly as the limitations of experiment allow, the absolute electrical quantities in terms of their theoretical relations to length, mass, and time. The international watt thus defined is the closest concrete realization of the theoretical absolute or mechanical watt which we have. We cannot at the present time say whether the international watt is greater or less than the absolute or mechanical watt, but the difference is probably not greater than a few parts in 10,000. Consequently, there is in reality no confusion between the mechanical watt and the international electrical watt.

It is recommended that engineering societies and other interests concerned recognize the value of the "English and American horsepower" as 746 watts (or 550 foot-pounds per second at 50° latitude and sea level, approximately the latitude of London), employing Table 2 to obtain the value in foot-pounds per second at other places. It is likewise recommended that the value of the "continental horsepower" be taken uniformly as 736 watts (or 75 kilogrammeters per second at latitude 52° 30′, the latitude of Berlin), and that the value in kilogrammeters per second at other places be obtained from such a table as Table 5.

It is probably not generally known that these values were adopted by a committee of the British Association for the Advancement of Science in 1873. This was a committee which recommended the C. G. S. System, and on it were Sir W. Thomson, Carey Foster, Clerk Maxwell, J. D. Everett, and others (B. A. Report, 1873, p. 222). The committee in its report said: "One horsepower is about three-fourths of an erg-ten per second. More nearly, it is 7.46 erg-nines per second; and one force-de-cheval is 7.36 erg-nines per second." (One erg-nine = 100 watts.)

The Standards Committee of the American Institute of Electrical Engineers adopted, on May 16, 1911, the following rule, which was inserted in the Standardization Rules of the Institute:

In view of the fact that a horsepower defined as 550 foot-pounds per second represents a power which varies slightly with the latitude and altitude (from 743.3 to 747.6 watts), and also in view of the fact that different authorities differ as to the precise value of the horsepower in watts, the standards committee has adopted 746 watts as the value of the horsepower. The number of foot-pounds per second to be taken as one horsepower is, therefore, such a value at any given place as is equivalent to 746 watts; the number varies from 552 to 549 foot-pounds per second, being 550 at 50° latitude (London), and 550.5 at Washington. The Standards Committee, however, recommends that the kilowatt instead of the horsepower be used generally as the unit of power.

The same value, 746 watts, is used by the Bureau of Standards as the exact equivalent of the English and American horsepower. The Bureau recommends the use, whenever possible, of the kilowatt instead of the horsepower.

### Horsepowers to Kilowatts

Reduction factor: 1 horsepower = 0.746 kilowatts

| Horsepowers | Kilowatts | Horsepowers | Kilowatts | Horsepowers | Kilowatts | Horsepowers | Kilowatts | Horsepowers | Kilowatts | Horsepowers | Kilowatts |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | 10 = | 7.460 | 20 = | 14.920 | 30 = | 22.380 | 40 = | 29.840 | 50 = | 37.300 |
| 1 = | 0.746 | 1 | 8.206 | 1 | 15.666 | 1 | 23.126 | 1 | 30.586 | 1 | 38.046 |
| 2 | 1.492 | 2 | 8.952 | 2 | 16.412 | 2 | 23.872 | 2 | 31.332 | 2 | 38.792 |
| 3 | 2.238 | 3 | 9.698 | 3 | 17.158 | 3 | 24.618 | 3 | 32.078 | 3 | 39.538 |
| 4 | 2.984 | 4 | 10.444 | 4 | 17.904 | 4 | 25.364 | 4 | 32.824 | 4 | 40.284 |
| 5 | 3.730 | 5 | 11.190 | 5 | 18.650 | 5 | 26.110 | 5 | 33.570 | 5 | 41.030 |
| 6 | 4.476 | 6 | 11.936 | 6 | 19.396 | 6 | 26.856 | 6 | 34.316 | 6 | 41.776 |
| 7 | 5.222 | 7 | 12.682 | 7 | 20.142 | 7 | 27.602 | 7 | 35.062 | 7 | 42.522 |
| 8 | 5.968 | 8 | 13.428 | 8 | 20.888 | 8 | 28.348 | 8 | 35.808 | 8 | 43.268 |
| 9 | 6.714 | 9 | 14.174 | 9 | 21.634 | 9 | 29.094 | 9 | 36.554 | 9 | 44.014 |

## HORSEPOWERS TO KILOWATTS

| Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 60 = | 44.760 | 100 = | 74.60 | 140 = | 104.44 | 180 = | 134.28 | 220 = | 164.12 | 260 = | 193.96 |
| 1 | 45.506 | 1 | 75.35 | 1 | 105.19 | 1 | 135.03 | 1 | 164.87 | 1 | 194.71 |
| 2 | 46.252 | 2 | 76.09 | 2 | 105.93 | 2 | 135.77 | 2 | 165.61 | 2 | 195.45 |
| 3 | 46.998 | 3 | 76.84 | 3 | 106.68 | 3 | 136.52 | 3 | 166.36 | 3 | 196.20 |
| 4 | 47.744 | 4 | 77.58 | 4 | 107.42 | 4 | 137.26 | 4 | 167.10 | 4 | 196.94 |
| 5 | 48.490 | 5 | 78.33 | 5 | 108.17 | 5 | 138.01 | 5 | 167.85 | 5 | 197.69 |
| 6 | 49.236 | 6 | 79.08 | 6 | 108.92 | 6 | 138.76 | 6 | 168.60 | 6 | 198.44 |
| 7 | 49.982 | 7 | 79.82 | 7 | 109.66 | 7 | 139.50 | 7 | 169.34 | 7 | 199.18 |
| 8 | 50.728 | 8 | 80.57 | 8 | 110.41 | 8 | 140.25 | 8 | 170.09 | 8 | 199.93 |
| 9 | 51.474 | 9 | 81.31 | 9 | 111.15 | 9 | 140.99 | 9 | 170.83 | 9 | 200.67 |
| 70 = | 52.220 | 110 = | 82.06 | 150 = | 111.90 | 190 = | 141.74 | 230 = | 171.58 | 270 = | 201.42 |
| 1 | 52.966 | 1 | 82.81 | 1 | 112.65 | 1 | 142.49 | 1 | 172.33 | 1 | 202.17 |
| 2 | 53.712 | 2 | 83.55 | 2 | 113.39 | 2 | 143.23 | 2 | 173.07 | 2 | 202.91 |
| 3 | 54.458 | 3 | 84.30 | 3 | 114.14 | 3 | 143.98 | 3 | 173.82 | 3 | 203.66 |
| 4 | 55.204 | 4 | 85.04 | 4 | 114.88 | 4 | 144.72 | 4 | 174.56 | 4 | 204.40 |
| 5 | 55.950 | 5 | 85.79 | 5 | 115.63 | 5 | 145.47 | 5 | 175.31 | 5 | 205.15 |
| 6 | 56.696 | 6 | 86.54 | 6 | 116.38 | 6 | 146.22 | 6 | 176.06 | 6 | 205.90 |
| 7 | 57.442 | 7 | 87.28 | 7 | 117.12 | 7 | 146.96 | 7 | 176.80 | 7 | 206.64 |
| 8 | 58.188 | 8 | 88.03 | 8 | 117.87 | 8 | 147.71 | 8 | 177.55 | 8 | 207.39 |
| 9 | 58.934 | 9 | 88.77 | 9 | 118.61 | 9 | 148.45 | 9 | 178.29 | 9 | 208.13 |
| 80 = | 59.680 | 120 = | 89.52 | 160 = | 119.36 | 200 = | 149.20 | 240 = | 179.04 | 280 = | 208.88 |
| 1 | 60.426 | 1 | 90.27 | 1 | 120.11 | 1 | 149.95 | 1 | 179.79 | 1 | 209.63 |
| 2 | 61.172 | 2 | 91.01 | 2 | 120.85 | 2 | 150.69 | 2 | 180.53 | 2 | 210.37 |
| 3 | 61.918 | 3 | 91.76 | 3 | 121.60 | 3 | 151.44 | 3 | 181.28 | 3 | 211.12 |
| 4 | 62.664 | 4 | 92.50 | 4 | 122.34 | 4 | 152.18 | 4 | 182.02 | 4 | 211.86 |
| 5 | 63.410 | 5 | 93.25 | 5 | 123.09 | 5 | 152.93 | 5 | 182.77 | 5 | 212.61 |
| 6 | 64.156 | 6 | 94.00 | 6 | 123.84 | 6 | 153.68 | 6 | 183.52 | 6 | 213.36 |
| 7 | 64.902 | 7 | 94.74 | 7 | 124.58 | 7 | 154.42 | 7 | 184.26 | 7 | 214.10 |
| 8 | 65.648 | 8 | 95.49 | 8 | 125.33 | 8 | 155.17 | 8 | 185.01 | 8 | 214.85 |
| 9 | 66.394 | 9 | 96.23 | 9 | 126.07 | 9 | 155.91 | 9 | 185.75 | 9 | 215.59 |
| 90 = | 67.140 | 130 = | 96.98 | 170 = | 126.82 | 210 = | 156.66 | 250 = | 186.50 | 290 = | 216.34 |
| 1 | 67.886 | 1 | 97.73 | 1 | 127.57 | 1 | 157.41 | 1 | 187.25 | 1 | 217.09 |
| 2 | 68.632 | 2 | 98.47 | 2 | 128.31 | 2 | 158.15 | 2 | 187.99 | 2 | 217.83 |
| 3 | 69.378 | 3 | 99.22 | 3 | 129.06 | 3 | 158.90 | 3 | 188.74 | 3 | 218.58 |
| 4 | 70.124 | 4 | 99.96 | 4 | 129.80 | 4 | 159.64 | 4 | 189.48 | 4 | 219.32 |
| 5 | 70.870 | 5 | 100.71 | 5 | 130.55 | 5 | 160.39 | 5 | 190.23 | 5 | 220.07 |
| 6 | 71.616 | 6 | 101.46 | 6 | 131.30 | 6 | 161.14 | 6 | 190.98 | 6 | 220.82 |
| 7 | 72.362 | 7 | 102.20 | 7 | 132.04 | 7 | 161.88 | 7 | 191.72 | 7 | 221.56 |
| 8 | 73.108 | 8 | 102.95 | 8 | 132.79 | 8 | 162.63 | 8 | 192.47 | 8 | 222.31 |
| 9 | 73.854 | 9 | 103.69 | 9 | 133.53 | 9 | 163.37 | 9 | 193.21 | 9 | 223.05 |

## Horsepowers to Kilowatts

| Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 300 = | 223.80 | 340 = | 253.64 | 380 = | 283.48 | 420 = | 313.32 | 460 = | 343.16 | 500 = | 373.00 |
| 1 | 224.55 | 1 | 254.39 | 1 | 284.23 | 1 | 314.07 | 1 | 343.91 | 1 | 373.75 |
| 2 | 225.29 | 2 | 255.13 | 2 | 284.97 | 2 | 314.81 | 2 | 344.65 | 2 | 374.49 |
| 3 | 226.04 | 3 | 255.88 | 3 | 285.72 | 3 | 315.56 | 3 | 345.40 | 3 | 375.24 |
| 4 | 226.78 | 4 | 256.62 | 4 | 286.46 | 4 | 316.30 | 4 | 346.14 | 4 | 375.98 |
| 5 | 227.53 | 5 | 257.37 | 5 | 287.21 | 5 | 317.05 | 5 | 346.89 | 5 | 376.73 |
| 6 | 228.28 | 6 | 258.12 | 6 | 287.96 | 6 | 317.80 | 6 | 347.64 | 6 | 377.48 |
| 7 | 229.02 | 7 | 258.86 | 7 | 288.70 | 7 | 318.54 | 7 | 348.38 | 7 | 378.22 |
| 8 | 229.77 | 8 | 259.61 | 8 | 289.45 | 8 | 319.29 | 8 | 349.13 | 8 | 378.97 |
| 9 | 230.51 | 9 | 260.35 | 9 | 290.19 | 9 | 320.03 | 9 | 349.87 | 9 | 379.71 |
| 310 = | 231.26 | 350 = | 261.10 | 390 = | 290.94 | 430 = | 320.78 | 470 = | 350.62 | 510 = | 380.46 |
| 1 | 232.01 | 1 | 261.85 | 1 | 291.69 | 1 | 321.53 | 1 | 351.37 | 1 | 381.21 |
| 2 | 232.75 | 2 | 262.59 | 2 | 292.43 | 2 | 322.27 | 2 | 352.11 | 2 | 381.95 |
| 3 | 233.50 | 3 | 263.34 | 3 | 293.18 | 3 | 323.02 | 3 | 352.86 | 3 | 382.70 |
| 4 | 234.24 | 4 | 264.08 | 4 | 293.92 | 4 | 323.76 | 4 | 353.60 | 4 | 383.44 |
| 5 | 234.99 | 5 | 264.83 | 5 | 294.67 | 5 | 324.51 | 5 | 354.35 | 5 | 384.19 |
| 6 | 235.74 | 6 | 265.58 | 6 | 295.42 | 6 | 325.26 | 6 | 355.10 | 6 | 384.94 |
| 7 | 236.48 | 7 | 266.32 | 7 | 296.16 | 7 | 326.00 | 7 | 355.84 | 7 | 385.68 |
| 8 | 237.23 | 8 | 267.07 | 8 | 296.91 | 8 | 326.75 | 8 | 356.59 | 8 | 386.43 |
| 9 | 237.97 | 9 | 267.81 | 9 | 297.65 | 9 | 327.49 | 9 | 357.33 | 9 | 387.17 |
| 320 = | 238.72 | 360 = | 268.56 | 400 = | 298.40 | 440 = | 328.24 | 480 = | 358.08 | 520 = | 387.92 |
| 1 | 239.47 | 1 | 269.31 | 1 | 299.15 | 1 | 328.99 | 1 | 358.83 | 1 | 388.67 |
| 2 | 240.21 | 2 | 270.05 | 2 | 299.89 | 2 | 329.73 | 2 | 359.57 | 2 | 389.41 |
| 3 | 240.96 | 3 | 270.80 | 3 | 300.64 | 3 | 330.48 | 3 | 360.32 | 3 | 390.16 |
| 4 | 241.70 | 4 | 271.54 | 4 | 301.38 | 4 | 331.22 | 4 | 361.06 | 4 | 390.90 |
| 5 | 242.45 | 5 | 272.29 | 5 | 302.13 | 5 | 331.97 | 5 | 361.81 | 5 | 391.65 |
| 6 | 243.20 | 6 | 273.04 | 6 | 302.88 | 6 | 332.72 | 6 | 362.56 | 6 | 392.40 |
| 7 | 243.94 | 7 | 273.78 | 7 | 303.62 | 7 | 333.46 | 7 | 363.30 | 7 | 393.14 |
| 8 | 244.69 | 8 | 274.53 | 8 | 304.37 | 8 | 334.21 | 8 | 364.05 | 8 | 393.89 |
| 9 | 245.43 | 9 | 275.27 | 9 | 305.11 | 9 | 334.95 | 9 | 364.79 | 9 | 394.63 |
| 330 = | 246.18 | 370 = | 276.02 | 410 = | 305.86 | 450 = | 335.70 | 490 = | 365.54 | 530 = | 395.38 |
| 1 | 246.93 | 1 | 276.77 | 1 | 306.61 | 1 | 336.45 | 1 | 366.29 | 1 | 396.13 |
| 2 | 247.67 | 2 | 277.51 | 2 | 307.35 | 2 | 337.19 | 2 | 367.03 | 2 | 396.87 |
| 3 | 248.42 | 3 | 278.26 | 3 | 308.10 | 3 | 337.94 | 3 | 367.78 | 3 | 397.62 |
| 4 | 249.16 | 4 | 279.00 | 4 | 308.84 | 4 | 338.68 | 4 | 368.52 | 4 | 398.36 |
| 5 | 249.91 | 5 | 279.75 | 5 | 309.59 | 5 | 339.43 | 5 | 369.27 | 5 | 399.11 |
| 6 | 250.66 | 6 | 280.50 | 6 | 310.34 | 6 | 340.18 | 6 | 370.02 | 6 | 399.86 |
| 7 | 251.40 | 7 | 281.24 | 7 | 311.08 | 7 | 340.92 | 7 | 370.76 | 7 | 400.60 |
| 8 | 252.15 | 8 | 281.99 | 8 | 311.83 | 8 | 341.67 | 8 | 371.51 | 8 | 401.35 |
| 9 | 252.89 | 9 | 282.73 | 9 | 312.57 | 9 | 342.41 | 9 | 372.25 | 9 | 402.09 |

## Horsepowers to Kilowatts

| Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 540 = | 402.84 | 580 = | 432.68 | 620 = | 462.52 | 660 = | 492.36 | 700 = | 522.20 | 740 = | 552.04 |
| 1 | 403.59 | 1 | 433.43 | 1 | 463.27 | 1 | 493.11 | 1 | 522.95 | 1 | 552.79 |
| 2 | 404.33 | 2 | 434.17 | 2 | 464.01 | 2 | 493.85 | 2 | 523.69 | 2 | 553.53 |
| 3 | 405.08 | 3 | 434.92 | 3 | 464.76 | 3 | 494.60 | 3 | 524.44 | 3 | 554.28 |
| 4 | 405.82 | 4 | 435.66 | 4 | 465.50 | 4 | 495.34 | 4 | 525.18 | 4 | 555.02 |
| 5 | 406.57 | 5 | 436.41 | 5 | 466.25 | 5 | 496.09 | 5 | 525.93 | 5 | 555.77 |
| 6 | 407.32 | 6 | 437.16 | 6 | 467.00 | 6 | 496.84 | 6 | 526.68 | 6 | 556.52 |
| 7 | 408.06 | 7 | 437.90 | 7 | 467.74 | 7 | 497.58 | 7 | 527.42 | 7 | 557.26 |
| 8 | 408.81 | 8 | 438.65 | 8 | 468.49 | 8 | 498.33 | 8 | 528.17 | 8 | 558.01 |
| 9 | 409.55 | 9 | 439.39 | 9 | 469.23 | 9 | 499.07 | 9 | 528.91 | 9 | 558.75 |
| 550 = | 410.30 | 590 = | 440.14 | 630 = | 469.98 | 670 = | 499.82 | 710 = | 529.66 | 750 = | 559.50 |
| 1 | 411.05 | 1 | 440.89 | 1 | 470.73 | 1 | 500.57 | 1 | 530.41 | 1 | 560.25 |
| 2 | 411.79 | 2 | 441.63 | 2 | 471.47 | 2 | 501.31 | 2 | 531.15 | 2 | 560.99 |
| 3 | 412.54 | 3 | 442.38 | 3 | 472.22 | 3 | 502.06 | 3 | 531.90 | 3 | 561.74 |
| 4 | 413.28 | 4 | 443.12 | 4 | 472.96 | 4 | 502.80 | 4 | 532.64 | 4 | 562.48 |
| 5 | 414.03 | 5 | 443.87 | 5 | 473.71 | 5 | 503.55 | 5 | 533.39 | 5 | 563.23 |
| 6 | 414.78 | 6 | 444.62 | 6 | 474.46 | 6 | 504.30 | 6 | 534.14 | 6 | 563.98 |
| 7 | 415.52 | 7 | 445.36 | 7 | 475.20 | 7 | 505.04 | 7 | 534.88 | 7 | 564.72 |
| 8 | 416.27 | 8 | 446.11 | 8 | 475.95 | 8 | 505.79 | 8 | 535.63 | 8 | 565.47 |
| 9 | 417.01 | 9 | 446.85 | 9 | 476.69 | 9 | 506.53 | 9 | 536.37 | 9 | 566.21 |
| 560 = | 417.76 | 600 = | 447.60 | 640 = | 477.44 | 680 = | 507.28 | 720 = | 537.12 | 760 = | 566.96 |
| 1 | 418.51 | 1 | 448.35 | 1 | 478.19 | 1 | 508.03 | 1 | 537.87 | 1 | 567.71 |
| 2 | 419.25 | 2 | 449.09 | 2 | 478.93 | 2 | 508.77 | 2 | 538.61 | 2 | 568.45 |
| 3 | 419.99 | 3 | 449.84 | 3 | 479.68 | 3 | 509.52 | 3 | 539.36 | 3 | 569.20 |
| 4 | 420.74 | 4 | 450.58 | 4 | 480.42 | 4 | 510.26 | 4 | 540.10 | 4 | 569.94 |
| 5 | 421.49 | 5 | 451.33 | 5 | 481.17 | 5 | 511.01 | 5 | 540.85 | 5 | 570.69 |
| 6 | 422.42 | 6 | 452.08 | 6 | 481.92 | 6 | 511.76 | 6 | 541.60 | 6 | 571.44 |
| 7 | 422.98 | 7 | 452.82 | 7 | 482.66 | 7 | 512.50 | 7 | 542.34 | 7 | 572.18 |
| 8 | 423.73 | 8 | 453.57 | 8 | 483.41 | 8 | 513.25 | 8 | 543.09 | 8 | 572.93 |
| 9 | 424.47 | 9 | 454.31 | 9 | 484.15 | 9 | 513.99 | 9 | 543.83 | 9 | 573.67 |
| 570 = | 425.22 | 610 = | 455.06 | 650 = | 484.90 | 690 = | 514.74 | 730 = | 544.58 | 770 = | 574.42 |
| 1 | 425.97 | 1 | 455.81 | 1 | 485.65 | 1 | 515.49 | 1 | 545.33 | 1 | 575.17 |
| 2 | 426.71 | 2 | 456.55 | 2 | 486.39 | 2 | 516.23 | 2 | 546.07 | 2 | 575.91 |
| 3 | 427.46 | 3 | 457.30 | 3 | 487.14 | 3 | 516.98 | 3 | 546.82 | 3 | 576.66 |
| 4 | 428.20 | 4 | 458.04 | 4 | 487.88 | 4 | 517.72 | 4 | 547.56 | 4 | 577.40 |
| 5 | 428.95 | 5 | 458.79 | 5 | 488.63 | 5 | 518.47 | 5 | 548.31 | 5 | 578.15 |
| 6 | 429.70 | 6 | 459.54 | 6 | 489.38 | 6 | 519.22 | 6 | 549.06 | 6 | 578.90 |
| 7 | 430.44 | 7 | 460.28 | 7 | 490.12 | 7 | 519.96 | 7 | 549.80 | 7 | 579.64 |
| 8 | 431.19 | 8 | 461.03 | 8 | 490.87 | 8 | 520.71 | 8 | 550.55 | 8 | 580.39 |
| 9 | 431.93 | 9 | 461.77 | 9 | 491.61 | 9 | 521.45 | 9 | 551.29 | 9 | 581.13 |

## Horsepowers to Kilowatts

| Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 780 = | 581.88 | 820 = | 611.72 | 860 = | 641.56 | 900 = | 671.40 | 940 = | 701.24 | 980 = | 731.08 |
| 1 | 582.63 | 1 | 612.47 | 1 | 642.31 | 1 | 672.15 | 1 | 701.99 | 1 | 731.83 |
| 2 | 583.37 | 2 | 613.21 | 2 | 643.05 | 2 | 672.89 | 2 | 702.73 | 2 | 732.57 |
| 3 | 584.12 | 3 | 613.96 | 3 | 643.80 | 3 | 673.64 | 3 | 703.48 | 3 | 733.32 |
| 4 | 584.86 | 4 | 614.70 | 4 | 644.54 | 4 | 674.38 | 4 | 704.22 | 4 | 734.06 |
| 5 | 585.61 | 5 | 615.45 | 5 | 645.29 | 5 | 675.13 | 5 | 704.97 | 5 | 734.81 |
| 6 | 586.36 | 6 | 616.20 | 6 | 646.04 | 6 | 675.88 | 6 | 705.72 | 6 | 735.56 |
| 7 | 587.10 | 7 | 616.94 | 7 | 646.78 | 7 | 676.62 | 7 | 706.46 | 7 | 736.30 |
| 8 | 587.85 | 8 | 617.69 | 8 | 647.53 | 8 | 677.37 | 8 | 707.21 | 8 | 737.05 |
| 9 | 588.59 | 9 | 618.43 | 9 | 648.27 | 9 | 678.11 | 9 | 707.95 | 9 | 737.79 |
| 790 = | 589.34 | 830 = | 619.18 | 870 = | 649.02 | 910 = | 678.86 | 950 = | 708.70 | 990 = | 738.54 |
| 1 | 590.09 | 1 | 619.93 | 1 | 649.77 | 1 | 679.61 | 1 | 709.45 | 1 | 739.29 |
| 2 | 590.83 | 2 | 620.67 | 2 | 650.51 | 2 | 680.35 | 2 | 710.19 | 2 | 740.03 |
| 3 | 591.58 | 3 | 621.42 | 3 | 651.26 | 3 | 681.10 | 3 | 710.94 | 3 | 740.78 |
| 4 | 592.32 | 4 | 622.16 | 4 | 652.00 | 4 | 681.84 | 4 | 711.68 | 4 | 741.52 |
| 5 | 593.07 | 5 | 622.91 | 5 | 652.75 | 5 | 682.59 | 5 | 712.43 | 5 | 742.27 |
| 6 | 593.82 | 6 | 623.66 | 6 | 653.50 | 6 | 683.34 | 6 | 713.18 | 6 | 743.02 |
| 7 | 594.56 | 7 | 624.40 | 7 | 654.24 | 7 | 684.08 | 7 | 713.92 | 7 | 743.76 |
| 8 | 595.31 | 8 | 625.15 | 8 | 654.99 | 8 | 684.83 | 8 | 714.67 | 8 | 744.51 |
| 9 | 596.05 | 9 | 625.89 | 9 | 655.73 | 9 | 685.57 | 9 | 715.41 | 9 | 745.25 |
| 800 = | 596.80 | 840 = | 626.64 | 880 = | 656.48 | 920 = | 686.32 | 960 = | 716.16 | 1000 = | 746 |
| 1 | 597.55 | 1 | 627.39 | 1 | 657.23 | 1 | 687.07 | 1 | 716.91 | 2000 = | 1492 |
| 2 | 598.29 | 2 | 628.13 | 2 | 657.97 | 2 | 687.81 | 2 | 717.65 | 3000 = | 2238 |
| 3 | 599.04 | 3 | 628.88 | 3 | 658.72 | 3 | 688.56 | 3 | 718.40 | 4000 = | 2984 |
| 4 | 599.78 | 4 | 629.62 | 4 | 659.46 | 4 | 689.30 | 4 | 719.14 | 5000 = | 3730 |
| 5 | 600.53 | 5 | 630.37 | 5 | 660.21 | 5 | 690.05 | 5 | 719.89 | 6000 = | 4476 |
| 6 | 601.28 | 6 | 631.12 | 6 | 660.96 | 6 | 690.80 | 6 | 720.64 | 7000 = | 5222 |
| 7 | 602.02 | 7 | 631.86 | 7 | 661.70 | 7 | 691.54 | 7 | 721.38 | 8000 = | 5968 |
| 8 | 602.77 | 8 | 632.61 | 8 | 662.45 | 8 | 692.29 | 8 | 722.13 | 9000 = | 6714 |
| 9 | 603.51 | 9 | 633.35 | 9 | 663.19 | 9 | 693.03 | 9 | 722.87 | 10000 = | 7460 |
| 810 = | 604.26 | 850 = | 634.10 | 890 = | 663.94 | 930 = | 693.78 | 970 = | 723.62 | | |
| 1 | 605.01 | 1 | 634.85 | 1 | 664.69 | 1 | 694.53 | 1 | 724.37 | | |
| 2 | 605.75 | 2 | 635.59 | 2 | 665.43 | 2 | 695.27 | 2 | 725.11 | | |
| 3 | 606.50 | 3 | 636.34 | 3 | 666.18 | 3 | 696.02 | 3 | 725.86 | | |
| 4 | 607.24 | 4 | 637.08 | 4 | 666.92 | 4 | 696.76 | 4 | 726.60 | | |
| 5 | 607.99 | 5 | 637.83 | 5 | 667.67 | 5 | 697.51 | 5 | 727.35 | | |
| 6 | 608.74 | 6 | 638.58 | 6 | 668.42 | 6 | 698.26 | 6 | 728.10 | | |
| 7 | 609.48 | 7 | 639.32 | 7 | 669.16 | 7 | 699.00 | 7 | 728.84 | | |
| 8 | 610.23 | 8 | 640.07 | 8 | 669.91 | 8 | 699.75 | 8 | 729.59 | | |
| 9 | 610.97 | 9 | 640.81 | 9 | 670.65 | 9 | 700.49 | 9 | 730.33 | | |

## Kilowatts to Horsepowers

Reduction factor: 1 kilowatt = 1.3404826 horsepower

| Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | 40= | 53.62 | 80= | 107.24 | 120= | 160.86 | 160= | 214.48 | 200= | 268.10 |
| 1 | 1.34 | 1 | 54.96 | 1 | 108.58 | 1 | 162.20 | 1 | 215.82 | 1 | 269.44 |
| 2 | 2.68 | 2 | 56.30 | 2 | 109.92 | 2 | 163.54 | 2 | 217.16 | 2 | 270.78 |
| 3 | 4.02 | 3 | 57.64 | 3 | 111.26 | 3 | 164.88 | 3 | 218.50 | 3 | 272.12 |
| 4 | 5.36 | 4 | 58.98 | 4 | 112.60 | 4 | 166.22 | 4 | 219.84 | 4 | 273.46 |
| 5 | 6.70 | 5 | 60.32 | 5 | 113.94 | 5 | 167.56 | 5 | 221.18 | 5 | 274.80 |
| 6 | 8.04 | 6 | 61.66 | 6 | 115.28 | 6 | 168.90 | 6 | 222.52 | 6 | 276.14 |
| 7 | 9.38 | 7 | 63.00 | 7 | 116.62 | 7 | 170.24 | 7 | 223.86 | 7 | 277.48 |
| 8 | 10.72 | 8 | 64.34 | 8 | 117.96 | 8 | 171.58 | 8 | 225.20 | 8 | 278.82 |
| 9 | 12.06 | 9 | 65.68 | 9 | 119.30 | 9 | 172.92 | 9 | 226.54 | 9 | 280.16 |
| 10= | 13.40 | 50= | 67.02 | 90= | 120.64 | 130= | 174.26 | 170= | 227.88 | 210= | 281.50 |
| 1 | 14.75 | 1 | 68.36 | 1 | 121.98 | 1 | 175.60 | 1 | 229.22 | 1 | 282.84 |
| 2 | 16.09 | 2 | 69.71 | 2 | 123.32 | 2 | 176.94 | 2 | 230.56 | 2 | 284.18 |
| 3 | 17.43 | 3 | 71.05 | 3 | 124.66 | 3 | 178.28 | 3 | 231.90 | 3 | 285.52 |
| 4 | 18.77 | 4 | 72.39 | 4 | 126.01 | 4 | 179.62 | 4 | 233.24 | 4 | 286.86 |
| 5 | 20.11 | 5 | 73.73 | 5 | 127.35 | 5 | 180.97 | 5 | 234.58 | 5 | 288.20 |
| 6 | 21.45 | 6 | 75.07 | 6 | 128.69 | 6 | 182.31 | 6 | 235.92 | 6 | 289.54 |
| 7 | 22.79 | 7 | 76.41 | 7 | 130.03 | 7 | 183.65 | 7 | 237.27 | 7 | 290.88 |
| 8 | 24.13 | 8 | 77.75 | 8 | 131.37 | 8 | 184.99 | 8 | 238.61 | 8 | 292.23 |
| 9 | 25.47 | 9 | 79.09 | 9 | 132.71 | 9 | 186.33 | 9 | 239.95 | 9 | 293.57 |
| 20= | 26.80 | 60= | 80.43 | 100= | 134.05 | 140= | 187.67 | 180= | 241.29 | 220= | 294.91 |
| 1 | 28.15 | 1 | 81.77 | 1 | 135.39 | 1 | 189.01 | 1 | 242.63 | 1 | 296.25 |
| 2 | 29.49 | 2 | 83.11 | 2 | 136.73 | 2 | 190.35 | 2 | 243.97 | 2 | 297.59 |
| 3 | 30.83 | 3 | 84.45 | 3 | 138.07 | 3 | 191.69 | 3 | 245.31 | 3 | 298.93 |
| 4 | 32.17 | 4 | 85.79 | 4 | 139.41 | 4 | 193.03 | 4 | 246.65 | 4 | 300.27 |
| 5 | 33.51 | 5 | 87.13 | 5 | 140.75 | 5 | 194.37 | 5 | 247.99 | 5 | 301.61 |
| 6 | 34.85 | 6 | 88.47 | 6 | 142.09 | 6 | 195.71 | 6 | 249.33 | 6 | 302.95 |
| 7 | 36.19 | 7 | 89.81 | 7 | 143.43 | 7 | 197.05 | 7 | 250.67 | 7 | 304.29 |
| 8 | 37.53 | 8 | 91.15 | 8 | 144.77 | 8 | 198.39 | 8 | 252.01 | 8 | 305.63 |
| 9 | 38.87 | 9 | 92.49 | 9 | 146.11 | 9 | 199.73 | 9 | 253.35 | 9 | 306.97 |
| 30= | 40.21 | 70= | 93.83 | 110= | 147.45 | 150= | 201.07 | 190= | 254.69 | 230= | 308.31 |
| 1 | 41.55 | 1 | 95.17 | 1 | 148.79 | 1 | 202.41 | 1 | 256.03 | 1 | 309.65 |
| 2 | 42.90 | 2 | 96.51 | 2 | 150.13 | 2 | 203.75 | 2 | 257.37 | 2 | 310.99 |
| 3 | 44.24 | 3 | 97.86 | 3 | 151.47 | 3 | 205.09 | 3 | 258.71 | 3 | 312.33 |
| 4 | 45.58 | 4 | 99.20 | 4 | 152.82 | 4 | 206.43 | 4 | 260.05 | 4 | 313.67 |
| 5 | 46.92 | 5 | 100.54 | 5 | 154.16 | 5 | 207.77 | 5 | 261.39 | 5 | 315.01 |
| 6 | 48.26 | 6 | 101.88 | 6 | 155.50 | 6 | 209.12 | 6 | 262.73 | 6 | 316.35 |
| 7 | 49.60 | 7 | 103.22 | 7 | 156.84 | 7 | 210.46 | 7 | 264.08 | 7 | 317.69 |
| 8 | 50.94 | 8 | 104.56 | 8 | 158.18 | 8 | 211.80 | 8 | 265.42 | 8 | 319.03 |
| 9 | 52.28 | 9 | 105.90 | 9 | 159.52 | 9 | 213.14 | 9 | 266.76 | 9 | 320.38 |

### Kilowatts to Horsepowers

| Kilowatts | Horsepowers | Kilowatts | Horsepowers | Kilowatts | Horsepowers | Kilowatts | Horsepowers | Kilowatts | Horsepowers | Kilowatts | Horsepowers |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 240= | 321.72 | 280= | 375.34 | 320= | 428.95 | 360= | 482.57 | 400= | 536.19 | 440= | 589.81 |
| 1 | 323.06 | 1 | 376.68 | 1 | 430.29 | 1 | 483.91 | 1 | 537.53 | 1 | 591.15 |
| 2 | 324.40 | 2 | 378.02 | 2 | 431.64 | 2 | 485.25 | 2 | 538.87 | 2 | 592.49 |
| 3 | 325.74 | 3 | 379.36 | 3 | 432.98 | 3 | 486.60 | 3 | 540.21 | 3 | 593.83 |
| 4 | 327.08 | 4 | 380.70 | 4 | 434.32 | 4 | 487.94 | 4 | 541.55 | 4 | 595.17 |
| 5 | 328.42 | 5 | 382.04 | 5 | 435.66 | 5 | 489.28 | 5 | 542.90 | 5 | 596.51 |
| 6 | 329.76 | 6 | 383.38 | 6 | 437.00 | 6 | 490.62 | 6 | 544.24 | 6 | 597.86 |
| 7 | 331.10 | 7 | 384.72 | 7 | 438.34 | 7 | 491.96 | 7 | 545.58 | 7 | 599.20 |
| 8 | 332.44 | 8 | 386.06 | 8 | 439.68 | 8 | 493.30 | 8 | 546.92 | 8 | 600.54 |
| 9 | 333.78 | 9 | 387.40 | 9 | 441.02 | 9 | 494.64 | 9 | 548.26 | 9 | 601.88 |
| 250= | 335.12 | 290= | 388.74 | 330= | 442.36 | 370= | 495.98 | 410= | 549.60 | 450= | 603.22 |
| 1 | 336.46 | 1 | 390.08 | 1 | 443.70 | 1 | 497.32 | 1 | 550.94 | 1 | 604.56 |
| 2 | 337.80 | 2 | 391.42 | 2 | 445.04 | 2 | 498.66 | 2 | 552.28 | 2 | 605.90 |
| 3 | 339.14 | 3 | 392.76 | 3 | 446.38 | 3 | 500.00 | 3 | 553.62 | 3 | 607.24 |
| 4 | 340.48 | 4 | 394.10 | 4 | 447.72 | 4 | 501.34 | 4 | 554.96 | 4 | 608.58 |
| 5 | 341.82 | 5 | 395.44 | 5 | 449.06 | 5 | 502.68 | 5 | 556.30 | 5 | 609.92 |
| 6 | 343.16 | 6 | 396.78 | 6 | 450.40 | 6 | 504.02 | 6 | 557.64 | 6 | 611.26 |
| 7 | 344.50 | 7 | 398.12 | 7 | 451.74 | 7 | 505.36 | 7 | 558.98 | 7 | 612.60 |
| 8 | 345.84 | 8 | 399.46 | 8 | 453.08 | 8 | 506.70 | 8 | 560.32 | 8 | 613.94 |
| 9 | 347.18 | 9 | 400.80 | 9. | 454.42 | 9 | 508.04 | 9 | 561.66 | 9 | 615.28 |
| 260= | 348.53 | 300= | 402.14 | 340= | 455.76 | 380= | 509.38 | 420= | 563.00 | 460= | 616.62 |
| 1 | 349.87 | 1 | 403.49 | 1 | 457.10 | 1 | 510.72 | 1 | 564.34 | 1 | 617.96 |
| 2 | 351.21 | 2 | 404.83 | 2 | 458.45 | 2 | 512.06 | 2 | 565.68 | 2 | 619.30 |
| 3 | 352.55 | 3 | 406.17 | 3 | 459.79 | 3 | 513.40 | 3 | 567.02 | 3 | 620.64 |
| 4 | 353.89 | 4 | 407.51 | 4 | 461.13 | 4 | 514.75 | 4 | 568.36 | 4 | 621.98 |
| 5 | 355.23 | 5 | 408.85 | 5 | 462.47 | 5 | 516.09 | 5 | 569.71 | 5 | 623.32 |
| 6 | 356.57 | 6 | 410.19 | 6 | 463.81 | 6 | 517.43 | 6 | 571.05 | 6 | 624.66 |
| 7 | 357.91 | 7 | 411.53 | 7 | 465.15 | 7 | 518.77 | 7 | 572.39 | 7 | 626.01 |
| 8 | 359.25 | 8 | 412.87 | 8 | 466.49 | 8 | 520.11 | 8 | 573.73 | 8 | 627.35 |
| 9 | 360.59 | 9 | 414.21 | 9 | 467.83 | 9 | 521.45 | 9 | 575.07 | 9 | 628.69 |
| 270= | 361.93 | 310= | 415.55 | 350= | 469.17 | 390= | 522.79 | 430= | 576.41 | 470= | 630.03 |
| 1 | 363.27 | 1 | 416.89 | 1 | 470.51 | 1 | 524.13 | 1 | 577.75 | 1 | 631.37 |
| 2 | 364.61 | 2 | 418.23 | 2 | 471.85 | 2 | 525.47 | 2 | 579.09 | 2 | 632.71 |
| 3 | 365.95 | 3 | 419.57 | 3 | 473.19 | 3 | 526.81 | 3 | 580.43 | 3 | 634.05 |
| 4 | 367.29 | 4 | 420.91 | 4 | 474.53 | 4 | 528.15 | 4 | 581.77 | 4 | 635.39 |
| 5 | 368.63 | 5 | 422.25 | 5 | 475.87 | 5 | 529.49 | 5 | 583.11 | 5 | 636.73 |
| 6 | 369.97 | 6 | 423.59 | 6 | 477.21 | 6 | 530.83 | 6 | 584.45 | 6 | 638.07 |
| 7 | 371.31 | 7 | 424.93 | 7 | 478.55 | 7 | 532.17 | 7 | 585.79 | 7 | 639.41 |
| 8 | 372.65 | 8 | 426.27 | 8 | 479.89 | 8 | 533.51 | 8 | 587.13 | 8 | 640.75 |
| 9 | 373.99 | 9 | 427.61 | 9 | 481.23 | 9 | 534.85 | 9 | 588.47 | 9 | 642.09 |

## Kilowatts to Horsepowers

| Kilowatts | Horsepowers | Kilowatts | Horsepowers | Kilowatts | Horsepowers | Kilowatts | Horsepowers | Kilowatts | Horsepowers | Kilowatts | Horsepowers |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 480= | 643.43 | 520= | 697.05 | 560= | 750.67 | 600= | 804.29 | 640= | 857.91 | 680= | 911.53 |
| 1 | 644.77 | 1 | 698.39 | 1 | 752.01 | 1 | 805.63 | 1 | 859.25 | 1 | 912.87 |
| 2 | 646.11 | 2 | 699.73 | 2 | 753.35 | 2 | 806.97 | 2 | 860.59 | 2 | 914.21 |
| 3 | 647.45 | 3 | 701.07 | 3 | 754.69 | 3 | 808.31 | 3 | 861.93 | 3 | 915.55 |
| 4 | 648.79 | 4 | 702.41 | 4 | 756.03 | 4 | 809.65 | 4 | 863.27 | 4 | 916.89 |
| 5 | 650.13 | 5 | 703.75 | 5 | 757.37 | 5 | 810.99 | 5 | 864.61 | 5 | 918.23 |
| 6 | 651.47 | 6 | 705.09 | 6 | 758.71 | 6 | 812.33 | 6 | 865.95 | 6 | 919.57 |
| 7 | 652.82 | 7 | 706.43 | 7 | 760.05 | 7 | 813.67 | 7 | 867.29 | 7 | 920.91 |
| 8 | 654.16 | 8 | 707.77 | 8 | 761.39 | 8 | 815.01 | 8 | 868.63 | 8 | 922.25 |
| 9 | 655.50 | 9 | 709.12 | 9 | 762.73 | 9 | 816.35 | 9 | 869.97 | 9 | 923.59 |
| 490= | 656.84 | 530= | 710.46 | 570= | 764.08 | 610= | 817.69 | 650= | 871.31 | 690= | 924.93 |
| 1 | 658.18 | 1 | 711.80 | 1 | 765.42 | 1 | 819.03 | 1 | 872.65 | 1 | 926.27 |
| 2 | 659.52 | 2 | 713.14 | 2 | 766.76 | 2 | 820.38 | 2 | 873.99 | 2 | 927.61 |
| 3 | 660.86 | 3 | 714.48 | 3 | 768.10 | 3 | 821.72 | 3 | 875.34 | 3 | 928.95 |
| 4 | 662.20 | 4 | 715.82 | 4 | 769.44 | 4 | 823.06 | 4 | 876.68 | 4 | 930.29 |
| 5 | 663.54 | 5 | 717.16 | 5 | 770.78 | 5 | 824.40 | 5 | 878.02 | 5 | 931.64 |
| 6 | 664.88 | 6 | 718.50 | 6 | 772.12 | 6 | 825.74 | 6 | 879.36 | 6 | 932.98 |
| 7 | 666.22 | 7 | 719.84 | 7 | 773.46 | 7 | 827.08 | 7 | 880.70 | 7 | 934.32 |
| 8 | 667.56 | 8 | 721.18 | 8 | 774.80 | 8 | 828.42 | 8 | 882.04 | 8 | 935.66 |
| 9 | 668.90 | 9 | 722.52 | 9 | 776.14 | 9 | 829.76 | 9 | 883.38 | 9 | 937.00 |
| 500= | 670.24 | 540= | 723.86 | 580= | 777.48 | 620= | 831.10 | 660= | 884.72 | 700= | 938.34 |
| 1 | 671.58 | 1 | 725.20 | 1 | 778.82 | 1 | 832.44 | 1 | 886.06 | 1 | 939.68 |
| 2 | 672.92 | 2 | 726.54 | 2 | 780.16 | 2 | 833.78 | 2 | 887.40 | 2 | 941.02 |
| 3 | 674.26 | 3 | 727.88 | 3 | 781.50 | 3 | 835.12 | 3 | 888.74 | 3 | 942.36 |
| 4 | 675.60 | 4 | 729.22 | 4 | 782.84 | 4 | 836.46 | 4 | 890.08 | 4 | 943.70 |
| 5 | 676.94 | 5 | 730.56 | 5 | 784.18 | 5 | 837.80 | 5 | 891.42 | 5 | 945.04 |
| 6 | 678.28 | 6 | 731.90 | 6 | 785.52 | 6 | 839.14 | 6 | 892.76 | 6 | 946.38 |
| 7 | 679.62 | 7 | 733.24 | 7 | 786.86 | 7 | 840.48 | 7 | 894.10 | 7 | 947.72 |
| 8 | 680.97 | 8 | 734.58 | 8 | 788.20 | 8 | 841.82 | 8 | 895.44 | 8 | 949.06 |
| 9 | 682.31 | 9 | 735.92 | 9 | 789.54 | 9 | 843.16 | 9 | 896.78 | 9 | 950.40 |
| 510= | 683.65 | 550= | 737.27 | 590= | 790.88 | 630= | 844.50 | 670= | 898.12 | 710= | 951.74 |
| 1 | 684.99 | 1 | 738.61 | 1 | 792.23 | 1 | 845.84 | 1 | 899.46 | 1 | 953.08 |
| 2 | 686.33 | 2 | 739.95 | 2 | 793.57 | 2 | 847.19 | 2 | 900.80 | 2 | 954.42 |
| 3 | 687.67 | 3 | 741.29 | 3 | 794.91 | 3 | 848.53 | 3 | 902.14 | 3 | 955.76 |
| 4 | 689.01 | 4 | 742.63 | 4 | 796.25 | 4 | 849.87 | 4 | 903.49 | 4 | 957.10 |
| 5 | 690.35 | 5 | 743.97 | 5 | 797.59 | 5 | 851.21 | 5 | 904.83 | 5 | 958.45 |
| 6 | 691.69 | 6 | 745.31 | 6 | 798.93 | 6 | 852.55 | 6 | 906.17 | 6 | 959.79 |
| 7 | 693.03 | 7 | 746.65 | 7 | 800.27 | 7 | 853.89 | 7 | 907.51 | 7 | 961.13 |
| 8 | 694.37 | 8 | 747.99 | 8 | 801.61 | 8 | 855.23 | 8 | 908.85 | 8 | 962.47 |
| 9 | 695.71 | 9 | 749.33 | 9 | 802.95 | 9 | 856.57 | 9 | 910.19 | 9 | 963.81 |

### Kilowatts to Horsepowers

| Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers | Kilo-watts | Horse-powers |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 720 = | 965.15 | 760 = | 1018.77 | 800 = | 1072.39 | 840 = | 1126.01 | 880 = | 1179.62 | 920 = | 1233.24 |
| 1 | 966.49 | 1 | 1020.10 | 1 | 1073.73 | 1 | 1127.35 | 1 | 1180.97 | 1 | 1234.58 |
| 2 | 967.83 | 2 | 1021.45 | 2 | 1075.07 | 2 | 1128.69 | 2 | 1182.31 | 2 | 1235.92 |
| 3 | 969.17 | 3 | 1022.79 | 3 | 1076.41 | 3 | 1130.03 | 3 | 1183.65 | 3 | 1237.27 |
| 4 | 970.51 | 4 | 1024.13 | 4 | 1077.75 | 4 | 1131.37 | 4 | 1184.99 | 4 | 1238.61 |
| 5 | 971.85 | 5 | 1025.47 | 5 | 1079.09 | 5 | 1132.71 | 5 | 1186.33 | 5 | 1239.95 |
| 6 | 973.19 | 6 | 1026.81 | 6 | 1080.43 | 6 | 1134.05 | 6 | 1187.67 | 6 | 1241.29 |
| 7 | 974.53 | 7 | 1028.15 | 7 | 1081.77 | 7 | 1135.39 | 7 | 1189.01 | 7 | 1242.63 |
| 8 | 975.87 | 8 | 1029.49 | 8 | 1083.11 | 8 | 1136.73 | 8 | 1190.35 | 8 | 1243.97 |
| 9 | 977.21 | 9 | 1030.83 | 9 | 1084.45 | 9 | 1138.07 | 9 | 1191.69 | 9 | 1245.31 |
| 730 = | 978.55 | 770 = | 1032.17 | 810 = | 1085.79 | 850 = | 1139.41 | 890 = | 1193.03 | 930 = | 1246.65 |
| 1 | 979.89 | 1 | 1033.51 | 1 | 1087.13 | 1 | 1140.75 | 1 | 1194.37 | 1 | 1247.99 |
| 2 | 981.23 | 2 | 1034.85 | 2 | 1088.47 | 2 | 1142.09 | 2 | 1195.71 | 2 | 1249.33 |
| 3 | 982.57 | 3 | 1036.19 | 3 | 1089.81 | 3 | 1143.43 | 3 | 1197.05 | 3 | 1250.67 |
| 4 | 983.91 | 4 | 1037.53 | 4 | 1091.15 | 4 | 1144.77 | 4 | 1198.39 | 4 | 1252.01 |
| 5 | 985.25 | 5 | 1038.87 | 5 | 1092.49 | 5 | 1146.11 | 5 | 1199.73 | 5 | 1253.35 |
| 6 | 986.60 | 6 | 1040.21 | 6 | 1093.83 | 6 | 1147.45 | 6 | 1201.07 | 6 | 1254.69 |
| 7 | 987.94 | 7 | 1041.55 | 7 | 1095.17 | 7 | 1148.79 | 7 | 1202.41 | 7 | 1256.03 |
| 8 | 989.28 | 8 | 1042.90 | 8 | 1096.51 | 8 | 1150.13 | 8 | 1203.75 | 8 | 1257.37 |
| 9 | 990.62 | 9 | 1044.24 | 9 | 1097.86 | 9 | 1151.47 | 9 | 1205.09 | 9 | 1258.71 |
| 740 = | 991.96 | 780 = | 1045.58 | 820 = | 1099.20 | 860 = | 1152.82 | 900 = | 1206.43 | 940 = | 1260.05 |
| 1 | 993.30 | 1 | 1046.92 | 1 | 1100.54 | 1 | 1154.16 | 1 | 1207.77 | 1 | 1261.39 |
| 2 | 994.64 | 2 | 1048.26 | 2 | 1101.88 | 2 | 1155.50 | 2 | 1209.12 | 2 | 1262.73 |
| 3 | 995.98 | 3 | 1049.60 | 3 | 1103.22 | 3 | 1156.84 | 3 | 1210.46 | 3 | 1264.08 |
| 4 | 997.32 | 4 | 1050.94 | 4 | 1104.56 | 4 | 1158.18 | 4 | 1211.80 | 4 | 1265.42 |
| 5 | 998.66 | 5 | 1052.28 | 5 | 1105.90 | 5 | 1159.52 | 5 | 1213.14 | 5 | 1266.76 |
| 6 | 1000.00 | 6 | 1053.62 | 6 | 1107.24 | 6 | 1160.86 | 6 | 1214.48 | 6 | 1268.10 |
| 7 | 1001.34 | 7 | 1054.96 | 7 | 1108.58 | 7 | 1162.20 | 7 | 1215.82 | 7 | 1269.44 |
| 8 | 1002.68 | 8 | 1056.30 | 8 | 1109.92 | 8 | 1163.54 | 8 | 1217.16 | 8 | 1270.78 |
| 9 | 1004.02 | 9 | 1057.64 | 9 | 1111.26 | 9 | 1164.88 | 9 | 1218.50 | 9 | 1272.12 |
| 750 = | 1005.36 | 790 = | 1058.98 | 830 = | 1112.60 | 870 = | 1166.22 | 910 = | 1219.84 | 950 = | 1273.46 |
| 1 | 1006.70 | 1 | 1060.32 | 1 | 1113.94 | 1 | 1167.56 | 1 | 1221.18 | 1 | 1274.80 |
| 2 | 1008.04 | 2 | 1061.66 | 2 | 1115.28 | 2 | 1168.90 | 2 | 1222.52 | 2 | 1276.14 |
| 3 | 1009.38 | 3 | 1063.00 | 3 | 1116.62 | 3 | 1170.24 | 3 | 1223.86 | 3 | 1277.48 |
| 4 | 1010.72 | 4 | 1064.34 | 4 | 1117.96 | 4 | 1171.58 | 4 | 1225.20 | 4 | 1278.82 |
| 5 | 1012.06 | 5 | 1065.68 | 5 | 1119.30 | 5 | 1172.92 | 5 | 1226.54 | 5 | 1280.16 |
| 6 | 1013.40 | 6 | 1067.02 | 6 | 1120.64 | 6 | 1174.26 | 6 | 1227.88 | 6 | 1281.50 |
| 7 | 1014.75 | 7 | 1068.36 | 7 | 1121.98 | 7 | 1175.60 | 7 | 1229.22 | 7 | 1282.84 |
| 8 | 1016.09 | 8 | 1069.71 | 8 | 1123.32 | 8 | 1176.94 | 8 | 1230.56 | 8 | 1284.18 |
| 9 | 1017.43 | 9 | 1071.05 | 9 | 1124.66 | 9 | 1178.28 | 9 | 1231.90 | 9 | 1285.52 |

## Kilowatts to Horsepowers

| Kilowatts | Horsepowers | Kilowatts | Horsepowers | Kilowatts | Horsepowers | Kilowatts | Horsepowers | Kilowatts | Horsepowers |
|---|---|---|---|---|---|---|---|---|---|
| 960 = | 1286.86 | 970 = | 1300.27 | 980 = | 1313.67 | 990 = | 1327.08 | 1000 = | 1340 |
| 1 | 1288.20 | 1 | 1301.61 | 1 | 1315.01 | 1 | 1328.42 | 2000 = | 2681 |
| 2 | 1289.54 | 2 | 1302.95 | 2 | 1316.35 | 2 | 1329.76 | 3000 = | 4021 |
| 3 | 1290.88 | 3 | 1304.29 | 3 | 1317.69 | 3 | 1331.10 | 4000 = | 5362 |
| 4 | 1292.23 | 4 | 1305.63 | 4 | 1319.03 | 4 | 1332.44 | 5000 = | 6702 |
| 5 | 1293.57 | 5 | 1306.97 | 5 | 1320.38 | 5 | 1333.78 | 6000 = | 8043 |
| 6 | 1294.91 | 6 | 1308.31 | 6 | 1321.72 | 6 | 1335.12 | 7000 = | 9383 |
| 7 | 1296.25 | 7 | 1309.65 | 7 | 1323.06 | 7 | 1336.46 | 8000 = | 10723 |
| 8 | 1297.59 | 8 | 1310.99 | 8 | 1324.40 | 8 | 1337.80 | 9000 = | 12064 |
| 9 | 1298.93 | 9 | 1312.33 | 9 | 1325.74 | 9 | 1339.14 | 10000 = | 13405 |

## SECTION 2

# WEIGHTS AND MEASURES

## MEASURES OF LENGTH

**Line Measurement** is used in measuring distances. Any convenient unit may be employed, as —inch, foot, yard or mile.

The standard unit of length is the yard.

In 1813 Mr. Hassler obtained for the use of the United States Coast Survey a standard brass bar 82 inches long, graduated by Troughton, of London. The graduations of this bar were accepted as corresponding at the temperature of 62° F. to the standard yard of Great Britain. The standard yard adopted by the United States Treasury Department was the 36 inches between the 27th and the 63d inches of the above 82-inch bar.

### LINEAR MEASURE

| | |
|---|---|
| 12 inches | = 1 foot |
| 3 feet | = 1 yard |
| $5\frac{1}{2}$ yards | = 1 rod |
| 320 rods | = 1 mile |

| mi. | rd. | yd. | ft. | in. |
|---|---|---|---|---|
| 1 = | 320 = | 1,760 = | 5,280 = | 63,360 |
| | 1 = | $5\frac{1}{2}$ = | $16\frac{1}{2}$ = | 198 |
| | | 1 = | 3 = | 36 |

The symbols: ′ for feet and ″ for inches are used in dimensioning drawings, often in books, and in correspondence.

EXAMPLE.—18′ 7″ = 18 feet 7 inches.

The foot is commonly divided for civil engineers into tenths and hundredths of a foot.

At the United States Custom Houses, the yard is divided into tenths and hundredths.

A mile of 5,280 ft. is called a statute mile. It is the legal mile of the United States and Great Britain.

**Surveyors' Linear Measure** is used in measuring land. The unit of this measure is Gunter's chain, 66 feet or 4 rods in length, having 100 links, each joined to the adjacent one by three smaller links. A square chain is one-tenth of an acre, or 10,000 square links.

### LAND MEASURES

| | |
|---|---|
| 100 links | = 1 chain |
| 80 chains | = 1 mile |

| mi. | ch. | ft. | l. | in. |
|---|---|---|---|---|
| 1 = | 80 = | 5,280 = | 8,000 = | 63,360 |
| | 1 = | 66 = | 100 = | 792 |
| | | 66 = | 1 = | 7.92 |

25 links = 1 rod
1 furlong = $\frac{1}{8}$ mile

City surveyors and civil engineers commonly use steel tapes 100 feet long, the feet divided into tenths and hundredths.

### OTHER LINEAR DIMENSIONS IN USE

| | | |
|---|---|---|
| 1 hand | = 4 inches. | Used in measuring the heights of horses. |
| 1 fathom | = 6 feet. | Used principally in nautical measurements; depth of water, length of rope, etc. It approximates the thousandth part of a nautical mile. |
| 1 cable | = 120 fathoms, or 720 feet; commonly written cable-length. | |
| 1 knot | = 1 nautical mile. | |
| | = 1 Admiralty knot = 6080 feet per hour. | |

NOTE.—A knot is a velocity, not a length. It is used to express the speed of a ship at sea. EXAMPLE.—15 knots per hour.

| | | |
|---|---|---|
| 1 geographical mile | = | 1.1515 statute miles; variously estimated from 6,075 to 6,080 ft. |
| | = | 1 minute of longitude at the equator. |
| | = | 1/60 degree of latitude. |
| 1 measured mile | = | English Admiralty "measured mile" is 6,080 feet; used to ascertain the speed of ships. |
| 1 league | = | 3 nautical miles. |
| 1 degree | = | 60 geographical miles; variously estimated from 69.21 to 69.29 statute miles. |
| | = | 1/360 part of the earth's circumference. |

## MEASURE OF SURFACE

A linear unit squared is a corresponding square unit in determining the areas of surfaces. The side of the square may be an inch, foot, yard, or any other convenient unit.

### SUPERFICIAL MEASURE

| | | |
|---|---|---|
| 144 square inches | = | 1 square foot |
| 9 square feet | = | 1 square yard |
| $30\frac{1}{4}$ square yards | = | 1 square rod |
| 160 square rods | = | 1 square acre |
| 640 acres | = | 1 square mile |
| 1 rood | = | $\frac{1}{4}$ acre. |

With the exception of the acre, the above units of superficial square measure are derived from the corresponding units of linear measure.

A square inch is the area of a rectangle the side of which is one inch.

A circular inch is the area of a circle one inch in diameter = 0.7854 square inch.

One square inch = 1.2732 circular inches.

One square foot = 144 square inches = 183.35 circular inches.

Slate and other roofing is often reckoned by the square, meaning 100 square feet of surface.

Plastering and painting are commonly reckoned by the square yard.

### SURVEYOR'S SQUARE MEASURE

| | | |
|---|---|---|
| 625 square links | = | 1 square rod |
| 16 square rods | = | 1 square chain |
| 10,000 square links | = | 1 square chain |
| 10 square chains | = | 1 acre |
| 640 acres | = | 1 square mile |
| 36 square miles | = | 1 township |

An acre is 208.71 feet square = 43,560 square feet. This is the common unit of land measure.

The public lands of the United States are divided by north and south meridianal lines crossed by others at right angles forming *Townships* of six miles square.

Townships are sub-divided into *Sections* one mile square.

A section one mile square contains 640 acres. It is divided into half-sections of 320 acres; quarter-sections of 160 acres; half-quarter sections of 80 acres; and quarter-quarter sections of 40 acres.

**Board Measure** is used in measuring lumber. The unit is 1 square foot of surface by 1 inch in thickness, or $\frac{1}{12}$ of a cubic foot.

Unless otherwise stated, boards less than an inch thick are reckoned as if they were of that thickness. Boards over an inch thick are reduced to the inch standard; that is, for $1\frac{1}{4}$-inch boards add $\frac{1}{4}$ to the surface measure, for $1\frac{1}{2}$-inch boards add $\frac{1}{2}$ to the surface measure, and so on for any thickness. All sawed timber is measured by board measure.

1,000 feet board measure = 83.33 cubic feet.

## MEASURES OF VOLUME

Cubic measure applies to measurement in the three dimensions of length, breadth, and depth or thickness. Any convenient linear unit may be employed because quantities are always expressed in cubes of fixed linear measurement, as cubic inch, cubic foot, or cubic yard.

### SOLID OR CUBIC MEASURE

| | | |
|---|---|---|
| 1,728 cubic inches | = | 1 cubic foot |
| 27 cubic feet | = | 1 cubic yard |
| 128 cubic feet | = | 1 cord |
| $24\frac{3}{4}$ cubic feet | = | 1 perch |

A perch of masonry is $16\frac{1}{2}$ feet long, $1\frac{1}{2}$ feet thick, and 1 foot high = $24\frac{3}{4}$ cubic feet.

A cord of wood is 8 feet long, 4 feet wide, and 4 feet high = 128 cubic feet.

Timber measured in bulk and not to be computed in cubic feet is reduced to board measure, that is, in terms of square feet of surface by 1 inch in thickness.

## MEASURES OF CAPACITY

The United States gallon corresponds to the British wine gallon of 1707, which was abolished in 1824, when the Imperial gallon, containing 10 pounds of water, was made the British standard. This latter measure is not in use in this country.

The unit of liquid measure in the United States is the wine gallon of 231 cubic inches.

### TABLE

| | | |
|---|---|---|
| 4 gills | = | 1 pint |
| 2 pints | = | 1 quart |
| 4 quarts | = | 1 gallon |

| gal. | | qt. | | pt. | | gi. |
|---|---|---|---|---|---|---|
| 1 | = | 4 | = | 8 | = | 32 |
| | | 1 | = | 2 | = | 8 |
| | | | | 1 | = | 4 |

1 gallon of pure water at 62° F. = 8.34 pounds.

1 cubic foot of water contains 7.48 gallons.

Barrels are not uniform in capacity, ranging from $31\frac{1}{2}$ to 50 gallons. Their capacity is found by gauging, actual measurement, or by weight.

Hogshead = 2 barrels. Actual capacity must be determined by gauging or other measurement.

**The British Imperial Gallon** is defined as the volume of 10 pounds weight of pure distilled water at the temperature of 62° F., the height of the barometer being 30 inches. There is no legal equivalent of the gallon expressed in cubic inches. Until the year 1890 it was usual to take 277.274 cubic inches as the equivalent of the gallon, but from very careful experiments by Mr. H. J. Chaney, recorded in the *Philosophical Transactions of the Royal Society* for 1892, the weight of a cubic inch of water was determined as 252.286 grains, from which the volume of the gallon is computed to be 277.463 cubic inches.

An Imperial gallon = 1.20114 United States gallons.

A United States gallon = 231 cubic inches = .83254 Imperial gallon.

## DRY MEASURE

Dry Measure is used in measuring grain, fruits, etc.

The unit in the United States is the Winchester bushel = 2,150.42 cubic inches = 1.244 cubic feet.

### TABLE

| | | |
|---|---|---|
| 2 pints | = | 1 quart |
| 8 quarts | = | 1 peck |
| 4 pecks | = | 1 bushel |

| bu. | | pk. | | qt. | | pt. |
|---|---|---|---|---|---|---|
| 1 | = | 4 | = | 32 | = | 64 |
| | | 1 | = | 8 | = | 16 |

1 bushel = 2,150.42 ÷ 231 = 9.30 wine gallons

The above is what is known as the struck bushel or the bushel measure even full. The heaped bushel is about one-quarter more, the cone being about 6 inches high.

A bushel measure is $18\frac{1}{2}$ inches diameter by 8 inches deep.

**The U. S. Standard Bushel** was fixed at 2,150.42 cubic inches. This is the same as the Winchester bushel, now abolished in the British system, substituting therefor as the legal bushel one containing 8 Imperial gallons, equivalent to 2,219.704 cubic inches or 1.284 cubic feet.

It will be seen that neither the gallon nor the bushel adopted by the U. S. Treasury Department is in accord with the British standards.

Grain in bulk is sold by weight. Commercial usage has established an equivalent number of pounds per bushel for the various kinds of grain as well as for other commodities shipped in bulk; these equivalent weights have been generally legalized throughout the United States.

## AVOIRDUPOIS WEIGHT

Commercial weights are always in terms of the Avoirdupois standard.

Troy weights are reserved for gold, silver, and precious stones. Apothecaries' weight is employed when compounding medicine.

The unit of Avoirdupois weight is the pound containing 7,000 Troy grains.

### Table of Tons of 2,000 Pounds

*Also known as Short or Net Tons*

| | | ton | cwt. | lb. | oz. |
|---|---|---|---|---|---|
| 16 ounces | = 1 pound | 1 = | 20 = | 2,000 = | 32,000 |
| 100 pounds | = 1 hundredweight | | 1 = | 100 = | 1,600 |
| 20 hundredweights | = 1 ton | | | 1 = | 16 |

The ounce is divided into halves and quarters.

The ton of 2,000 pounds is the standard ton of commerce.

### Table of Tons of 2,240 Pounds

*Also known as Long or Gross Tons*

| | | ton | cwt. | lb. | oz. |
|---|---|---|---|---|---|
| 16 ounces | = 1 pound | 1 = | 20 = | 2,240 = | 35,840 |
| 112 pounds | = 1 hundredweight | | 1 = | 112 = | 1,792 |
| 20 hundredweights | = 1 ton | | | 1 = | 16 |

One quarter = 28 pounds

The ton of 2,240 pounds is used for weighing ores, pig iron, steel rails, etc. It is used in U. S. Custom Houses for estimating ocean freights. It is the standard ton of Great Britain.

One shipping ton (for measuring cargo) = 40 cubic feet. In England, one shipping ton (for measuring cargo) = 42 cubic feet.

## TROY WEIGHT

**The Troy Pound** was the first standard to be adopted by Congress and put into practical use. It was the legalization of a certain brass Troy-pound-weight procured by the Minister of the United States at London, in the year 1827, for the use of the Mint, and now in the custody of the U. S. Mint at Philadelphia. This is the standard Troy pound, comformably to which the U. S. coinage is regulated. It is an exact copy of the Imperial Troy pound of Great Britain.

Troy weight is used chiefly in the weighing of gold, silver, and articles of jewelry. The unit of weight is the Troy pound.

## WEIGHTS AND MEASURES

**Table**

| | | lb. | | oz. | | pwt. | | gr. |
|---|---|---|---|---|---|---|---|---|
| 24 grains | = 1 pennyweight | 1 | = | 12 | = | 240 | = | 5,760 |
| 20 pennyweights | = 1 ounce | | | 1 | = | 20 | = | 480 |
| 12 ounces | = 1 pound | | | | | | | |

**Carat** is a term employed to express the commercial fineness of gold. An ounce is divided into 24 equal parts, one of which is called a carat. Pure gold is 24 carats fine; 18-carat gold is 18 parts pure gold and 6 parts alloy.

**A Carat Weight** when employed to weigh diamonds = 3.2 Troy grains.

The International 200-milligram carat went into effect in the United States, July 1, 1913, as the standard for weighing all kinds of gems and precious stones. By comparison, 1 milligram = .0154 Troy grains. Then .0154 × 200 = 3.08 Troy grains.

## APOTHECARIES' WEIGHT

The ounce in Apothecaries' weight is the same as the Troy ounce but differently divided. The grain and the pound are the same as the Troy standards.

There does not appear to be a standard unit in Apothecaries' weight, but from the fact that it is used in compounding medicines in small quantities, the ounce (Troy) would appear to be a convenient one inasmuch as chemicals for industrial use, when sold in large quantities, are commonly by Avoirdupois weight.

**Table**

| | | lb. | | ℥ | | ʒ | | ℈ | | gr. |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 grains | = 1 scruple. . .*sc.* or ℈ | 1 | = | 12 | = | 96 | = | 288 | = | 5,760 |
| 3 scruples | = 1 dram. . . .*dr.* or ʒ | | | 1 | = | 8 | = | 24 | = | 480 |
| 8 drams | = 1 ounce. . . .*oz.* or ℥ | | | | | 1 | = | 3 | = | 60 |
| 12 ounces | = 1 pound. . . .*lb.* or ℔ | | | | | | | | | |

The symbols always precede the number, thus: ℥ 4, ʒ 2, ℈ 1 = 4 oz., 2 dr., 1 scruple.

### Apothecaries' Fluid Measure

Used by physicians when prescribing and by apothecaries in compounding liquid medicines.

The gallon is the standard wine gallon of 231 cubic inches, of which the pint is one-eighth.

**Table**

| | | Cong. | | O. | | f ℥ | | f ʒ | | ♏ |
|---|---|---|---|---|---|---|---|---|---|---|
| 60 minims (♏) | = 1 fluid drachm . f ʒ | 1 | = | 8 | = | 128 | = | 1,024 | = | 61,440 |
| 8 fluid drachms | = 1 fluid ounce. . . f ℥ | | | 1 | = | 16 | = | 128 | = | 7,680 |
| 16 fluid ounces | = 1 pint. . . . . . . . . .O. | | | | | 1 | = | 8 | = | 480 |
| 8 pints | = 1 gallon. . . . .Cong. | | | | | | | 1 | = | 60 |

Cong., Latin **Congius**, gallon; O., Latin **octavius**, one-eighth.

### Medical Signs and Abbreviations

℞ (Lat. Recipe), take; āā, of each; ℔, pound; ℥, ounce; ʒ, drachm; ℈, scruple; ♏, minim, or drop; O or o, pint; f ℥, fluid ounce; f ʒ, fluid drachm; as, ℥ ss, half an ounce; ℥ i, one ounce; ℥ iss, one ounce and a half; ℥ ij, two ounces; gr., grain; Q. S., as much as sufficient; Ft. Mist., let a mixture be made; Ft. Haust., let a draught be made; Ad., add to; Ad lib., at pleasure; Aq., water; M., mix; Mac., macerate; Pulv., powder; Pil., pill; Solv., dissolve; St., let it stand; Sum., to be taken; D., dose; Dil., dilute; Filt., filter; Lot., a wash; Garg., a gargle; Hor. Decub., at bedtime; Inject., injection; Gtt., drops; ss, one-half; Ess., essence.

The symbols always precede the numbers to which they refer. The International Metric System has practically displaced the above system in laboratory work as well as in compounding medicines.

## UNITED STATES MONEY

The legal currency of the United States is based on the gold standard. Coins are of gold, silver, nickel, and copper. Authorized paper money includes gold certificates, silver certificates, United States notes, Treasury notes of 1890, and National bank notes.

The unit of value is the gold dollar of 25.8 grains.

**Table**

| | | E. | | $ | | d. | | c. | | m. |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 mills | = 1 cent | | | | | | | 1 | = | 10 |
| 10 cents | = 1 dime | | | | | 1 | = | 10 | = | 100 |
| 10 dimes | = 1 dollar | | | 1 | = | 10 | = | 100 | = | 1,000 |
| 10 dollars | = 1 eagle | 1 | = | 10 | = | 100 | = | 1,000 | = | 10,000 |

Gold coins are 90 per cent gold and 10 per cent alloy, consisting of silver and copper. Denominations, $20, $10, $5, $2.50.

Silver coins are 90 per cent silver and 10 per cent copper alloy. Standard silver dollar weighs 412.5 grains. Ratio to gold 15.988 to 1. Coinage ceased in 1905.

Subsidiary silver coins weigh 385.8 grains to the dollar. Ratio to gold 14.953 to 1. Denominations, 50 cents, 25 cents, 10 cents. Legal tender, not to exceed $10. Redeemable in " lawful money " at the Treasury in sums or multiples of $20.

Minor coins now consist of the 5-cent and the 1-cent pieces only. The 5-cent piece weighs 77.16 grains. Alloy consists of 75 per cent copper and 25 per cent nickel.

The 1-cent piece weighs 48 grains. Alloy consists of 95 per cent copper and 5 per cent tin and zinc. They are legal tender not to exceed 25 cents. Redeemable in " lawful money " at the Treasury in sums or multiples of $20.

" Lawful money " includes gold coin, silver dollars, United States notes, and Treasury notes.

United States notes (greenbacks) are by regulation receivable for customs so long as they continue redeemable in coin. Treasury notes were issued for purchase of silver bullion which was coined into dollars, wherewith the notes are being redeemed.

## MEASURES OF TIME

A solar day is the period of one revolution of the earth around its axis in reference to the sun. It is divided into 24 hours, in two periods of 12 hours each; from 12 o'clock noon or meridian to 12 o'clock midnight, and from midnight to noon. The change in the name and number of days and months in the civil calendar occurs at midnight.

**Table**

| | | day | | hr. | | min. | | sec. |
|---|---|---|---|---|---|---|---|---|
| 60 seconds | = 1 minute | 1 | = | 24 | = | 1,440 | = | 86,400 |
| 60 minutes | = 1 hour | | | 1 | = | 60 | = | 3,600 |
| 24 hours | = 1 day | | | | | 1 | = | 60 |
| 7 days | = 1 week | | | | | | | |
| 365 days | = 1 calendar year | | | | | | | |

The length of the solar year is 365 days, 5 hr., 48 min., nearly. A calendar year of 365 days is nearly one-fourth of a day too short, for which one day is added to the month of February every four years, called leap-year. But this addition makes one day too much in every 128.866 years, which error is corrected every fourth century, which can be divided by four without a remainder. Thus, 1884 was leap-year, but not 1900, this omission of one leap-year in every four centuries being necessary to correct the error above referred to.

A sidereal day differs from a solar day in taking no account of the sun, but recording that interval of time between the appearance of a fixed star in the meridian and again returning to the same star the night immediately following. This interval of

## UNITED STATES MONEY EQUIVALENTS

### Value of Foreign Coins in United States Money

| Country | Standard | Monetary Unit | Value in U. S. Gold Dollar | Remarks (a) |
|---|---|---|---|---|
| Argentina | Gold | Peso | $0.9648 | Currency: depreciated paper, convertible at 44 per cent of face value. |
| Austria-Hungary | Gold | Crown | .2026 | |
| Belgium | Gold (b) | Franc | .1930 | Member of Latin Union; gold is the actual standard. |
| Bolivia | Gold | Boliviano | .3893 | 12½ bolivianos equal 1 pound sterling. |
| Brazil | Gold | Milreis | .5462 | Currency: Government paper. Exchange rate about $0.25 to the milreis. |
| British Colonies in Australia & Africa | Gold | Pound sterling | 4.8665 | |
| Canada | Gold | Dollar | 1.0000 | |
| Cent. American States: | | | | |
| B. Hond's. | Gold | Dollar | 1.0000 | |
| Costa Rica | Gold | Colon | .4653 | |
| Guat'ala | Silver | Peso | .3537 | Currency: inconvertible paper, exchange rate 40 pesos = $1.00. |
| Honduras | Silver | Peso | .3537 | Currency: bank notes. |
| Nicaragua | Gold | Cordoba | 1.0000 | |
| Salvador | Silver | Peso | .3537 | Currency: convertible into silver on demand. |
| Chile | Gold | Peso | .3650 | Currency: inconvertible paper; exchange rate approximately, $0.14. |
| China | Silver | Tael: Shanghai | .5296 | |
| | | Tael: Haikwan | .5899 | |
| | | Tael: Canton | .5780 | |
| Colombia | Gold | Dollar | 1.0000 | Currency: inconvertible paper; exchange rate, approximately, $105 paper to $1 gold. |
| Cuba | Gold | Peso | 1.0000 | |
| Denmark | Gold | Crown | .2680 | |
| Ecuador | Gold | Sucre | .4867 | |
| Egypt | Gold | Pound (100 piasters) | 4.9431 | The actual standard is the British pound sterling, which is legal tender for 97½ piasters. |
| Finland | Gold | Mark | .1930 | |
| France | Gold (b) | Franc | .1930 | Member of Latin Union; gold is the actual standard. |
| Germany | Gold | Mark | .2382 | |
| Gt. Britain | Gold | Pound sterling | 4.8665 | |
| Greece | Gold (b) | Drachma | .1930 | Member of Latin Union; gold is the actual standard. |
| Hayti | Gold | Gourde | .9647 | Currency: inconvertible paper; exchange rate, approximately, $0.16. |
| India | Gold | Rupee | .3244 | (15 rupees equal 1 pound sterling.) |

(a) The exchange rates shown under this heading are recent quotations and given as an indication of the values of currencies which are fluctuating in their relation to the legal standard. They are not to take the place of the Consular certificate where it is available. (b) And silver.

Value of Foreign Coins in United States Money—(*Cont.*)

| Country | Standard | Monetary Unit | Value in U. S. Gold Dollar | Remarks (a) |
|---|---|---|---|---|
| Italy...... | Gold (b) | Lira......... | .1930 | Member of Latin Union; gold is the actual standard. |
| Japan..... | Gold... | Yen......... | .4985 | |
| Liberia.... | Gold... | Dollar....... | 1.0000 | Currency: depreciated silver token coins; customs duties are collected in gold. |
| Mexico.... | Gold... | Peso......... | .4985 | Mexican exchange rate fluctuating, approximately, $0.15. |
| Netherlands. | Gold... | Florin....... | .4020 | |
| Newfoundland | Gold... | Dollar....... | 1.0139 | |
| Norway... | Gold... | Crown....... | .2680 | |
| Panama... | Gold... | Balboa....... | 1.0000 | |
| Paraguay.. | Silver.. | Peso......... | .3537 | Currency: depreciated paper; exchange rate 1.550 per cent. |
| Persia..... | Gold (b) | Kran........ | .1700 | This is the value of the gold kran. Currency is silver circulating above its metallic value; exchange value of silver kran, approximately, $0.0875. |
| Peru...... | Gold... | Libra........ | 4.8665 | |
| Philippine Islands... | Gold... | Peso......... | .5000 | |
| Portugal... | Gold... | Escudo...... | 1.0806 | Currency: inconvertible paper; exchange rate, approximately, $0.70½. |
| Roumania. | Gold... | Leu......... | .1930 | |
| Russia.... | Gold... | Ruble....... | .5146 | |
| Santo Dom | Gold... | Dollar....... | 1.0000 | |
| Serbia..... | Gold... | Dinar........ | .1930 | |
| Siam...... | Gold... | Tical........ | .3709 | |
| Spain..... | Gold (b) | Peseta....... | .1930 | Valuation is for the gold peseta; currency is silver circulating above its metallic value; exchange value, approximately, $0.20. |
| Straits Set'm'ts.. | Gold... | Dollar....... | .5678 | |
| Sweden... | Gold... | Crown....... | .2680 | |
| Switzerl'd . | Gold... | Franc........ | .1930 | Member Latin Union; gold is actual standard. |
| Turkey.... | Gold... | Piaster....... | .0440 | 100 piasters equal to the Turkish £. |
| Uruguay.. | Gold... | Peso......... | 1.0342 | |
| Venezuela. | Gold... | Bolivar...... | .1930 | |

(a) The exchange rates shown under this heading are recent quotations and given as an indication of the values of currencies which are fluctuating in their relation to the legal standard. They are not to take the place of the Consular certificate where it is available. (b) And silver.

time is divided into 24 hours continuously beginning at 1 P. M. and not into two periods of 12 hours each. Let there be two clocks, one regulated for mean solar time, indicating 24 hours from meridian to meridian of a fixed star; the latter clock will indicate only 23 hr., 56 min., 4 sec., of mean solar time; the fixed star passing the meridian 3 min., 56 sec., earlier every day.

A sidereal year is the time which elapses during a complete revolution of the earth around the sun, measured by the recurrence of the same fixed star selected at the beginning of the observation; it is 365 days, 6 hrs., 9 min., 9.3145 sec. of mean solar time.

NUMBER OF DAYS BETWEEN ANY TWO DAYS WITHIN TWO YEARS

| Day Mo. | Jan. | Feb. | Mar | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Day Mo. | Jan. | Feb. | Mar. | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 32 | 60 | 91 | 121 | 152 | 182 | 213 | 244 | 274 | 305 | 335 | 1 | 366 | 397 | 425 | 456 | 486 | 517 | 547 | 578 | 609 | 639 | 670 | 700 |
| 2 | 2 | 33 | 61 | 92 | 122 | 153 | 183 | 214 | 245 | 275 | 306 | 336 | 2 | 367 | 398 | 426 | 457 | 487 | 518 | 548 | 579 | 610 | 640 | 671 | 701 |
| 3 | 3 | 34 | 62 | 93 | 123 | 154 | 184 | 215 | 246 | 276 | 307 | 337 | 3 | 368 | 399 | 427 | 458 | 488 | 519 | 549 | 580 | 611 | 641 | 672 | 702 |
| 4 | 4 | 35 | 63 | 94 | 124 | 155 | 185 | 216 | 247 | 277 | 308 | 338 | 4 | 369 | 400 | 428 | 459 | 489 | 520 | 550 | 581 | 612 | 642 | 673 | 703 |
| 5 | 5 | 36 | 64 | 95 | 125 | 156 | 186 | 217 | 248 | 278 | 309 | 339 | 5 | 370 | 401 | 429 | 460 | 490 | 521 | 551 | 582 | 613 | 643 | 674 | 704 |
| 6 | 6 | 37 | 65 | 96 | 126 | 157 | 187 | 218 | 249 | 279 | 310 | 340 | 6 | 371 | 402 | 430 | 461 | 491 | 522 | 552 | 583 | 614 | 644 | 675 | 705 |
| 7 | 7 | 38 | 66 | 97 | 127 | 158 | 188 | 219 | 250 | 280 | 311 | 341 | 7 | 372 | 403 | 431 | 462 | 492 | 523 | 553 | 584 | 615 | 645 | 676 | 706 |
| 8 | 8 | 39 | 67 | 98 | 128 | 159 | 189 | 220 | 251 | 281 | 312 | 342 | 8 | 373 | 404 | 432 | 463 | 493 | 524 | 554 | 585 | 616 | 646 | 677 | 707 |
| 9 | 9 | 40 | 68 | 99 | 129 | 160 | 190 | 221 | 252 | 282 | 313 | 343 | 9 | 374 | 405 | 433 | 464 | 494 | 525 | 555 | 586 | 617 | 647 | 678 | 708 |
| 10 | 10 | 41 | 69 | 100 | 130 | 161 | 191 | 222 | 253 | 283 | 314 | 344 | 10 | 375 | 406 | 434 | 465 | 495 | 526 | 556 | 587 | 618 | 648 | 679 | 709 |
| 11 | 11 | 42 | 70 | 101 | 131 | 162 | 192 | 223 | 254 | 284 | 315 | 345 | 11 | 376 | 407 | 435 | 466 | 496 | 527 | 557 | 588 | 619 | 649 | 680 | 710 |
| 12 | 12 | 43 | 71 | 102 | 132 | 163 | 193 | 224 | 255 | 285 | 316 | 346 | 12 | 377 | 408 | 436 | 467 | 497 | 528 | 558 | 589 | 620 | 650 | 681 | 711 |
| 13 | 13 | 44 | 72 | 103 | 133 | 164 | 194 | 225 | 256 | 286 | 317 | 347 | 13 | 378 | 409 | 437 | 468 | 498 | 529 | 559 | 590 | 621 | 651 | 682 | 712 |
| 14 | 14 | 45 | 73 | 104 | 134 | 165 | 195 | 226 | 257 | 287 | 318 | 348 | 14 | 379 | 410 | 438 | 469 | 499 | 530 | 560 | 591 | 622 | 652 | 683 | 713 |
| 15 | 15 | 46 | 74 | 105 | 135 | 166 | 196 | 227 | 258 | 288 | 319 | 349 | 15 | 380 | 411 | 439 | 470 | 500 | 531 | 561 | 592 | 623 | 653 | 684 | 714 |
| 16 | 16 | 47 | 75 | 106 | 136 | 167 | 197 | 228 | 259 | 289 | 320 | 350 | 16 | 381 | 412 | 440 | 471 | 501 | 532 | 562 | 593 | 624 | 654 | 685 | 715 |
| 17 | 17 | 48 | 76 | 107 | 137 | 168 | 198 | 229 | 260 | 290 | 321 | 351 | 17 | 382 | 413 | 441 | 472 | 502 | 533 | 563 | 594 | 625 | 655 | 686 | 716 |
| 18 | 18 | 49 | 77 | 108 | 138 | 169 | 199 | 230 | 261 | 291 | 322 | 352 | 18 | 383 | 414 | 442 | 473 | 503 | 534 | 564 | 595 | 626 | 656 | 687 | 717 |
| 19 | 19 | 50 | 78 | 109 | 139 | 170 | 200 | 231 | 262 | 292 | 323 | 353 | 19 | 384 | 415 | 443 | 474 | 504 | 535 | 565 | 596 | 627 | 657 | 688 | 718 |
| 20 | 20 | 51 | 79 | 110 | 140 | 171 | 201 | 232 | 263 | 293 | 324 | 354 | 20 | 385 | 416 | 444 | 475 | 505 | 536 | 566 | 597 | 628 | 658 | 689 | 719 |
| 21 | 21 | 52 | 80 | 111 | 141 | 172 | 202 | 233 | 264 | 294 | 325 | 355 | 21 | 386 | 417 | 445 | 476 | 506 | 537 | 567 | 598 | 629 | 659 | 690 | 720 |
| 22 | 22 | 53 | 81 | 112 | 142 | 173 | 203 | 234 | 265 | 295 | 326 | 356 | 22 | 387 | 418 | 446 | 477 | 507 | 538 | 568 | 599 | 630 | 660 | 691 | 721 |
| 23 | 23 | 54 | 82 | 113 | 143 | 174 | 204 | 235 | 266 | 296 | 327 | 357 | 23 | 388 | 419 | 447 | 478 | 508 | 539 | 569 | 600 | 631 | 661 | 692 | 722 |
| 24 | 24 | 55 | 83 | 114 | 144 | 175 | 205 | 236 | 267 | 297 | 328 | 358 | 24 | 389 | 420 | 448 | 479 | 509 | 540 | 570 | 601 | 632 | 662 | 693 | 723 |
| 25 | 25 | 56 | 84 | 115 | 145 | 176 | 206 | 237 | 268 | 298 | 329 | 359 | 25 | 390 | 421 | 449 | 480 | 510 | 541 | 571 | 602 | 633 | 663 | 694 | 724 |
| 26 | 26 | 57 | 85 | 116 | 146 | 177 | 207 | 238 | 269 | 299 | 330 | 360 | 26 | 391 | 422 | 450 | 481 | 511 | 542 | 572 | 603 | 634 | 664 | 695 | 725 |
| 27 | 27 | 58 | 86 | 117 | 147 | 178 | 208 | 239 | 270 | 300 | 331 | 361 | 27 | 392 | 423 | 451 | 482 | 512 | 543 | 573 | 604 | 635 | 665 | 696 | 726 |
| 28 | 28 | 59 | 87 | 118 | 148 | 179 | 209 | 240 | 271 | 301 | 332 | 362 | 28 | 393 | 424 | 452 | 483 | 513 | 544 | 574 | 605 | 636 | 666 | 697 | 727 |
| 29 | 29 | .. | 88 | 119 | 149 | 180 | 210 | 241 | 272 | 302 | 333 | 363 | 29 | 394 | ... | 453 | 484 | 514 | 545 | 575 | 606 | 637 | 667 | 698 | 728 |
| 30 | 30 | .. | 89 | 120 | 150 | 181 | 211 | 242 | 273 | 303 | 334 | 364 | 30 | 395 | ... | 454 | 485 | 515 | 546 | 576 | 607 | 638 | 668 | 699 | 729 |
| 31 | 31 | .. | 90 | ... | 151 | ... | 212 | 243 | ... | 304 | ... | 365 | 31 | 396 | ... | 455 | ... | 516 | ... | 577 | 608 | ... | 669 | ... | 730 |

EXAMPLE.—The number of days from October 18 to the following June 9 = 525 − 291 = 234 days. Method: beginning with the later date in left-hand column, 9 day, trace across table the June in second year, finding 525; then from 18 day in left-hand column trace across table to October in first year finding 291, subtracting this number from the former = 234 days.

EXAMPLE.—To find the date upon which a note given March 11 for 45 days will become due: Find 11 day in left-hand column; trace across table to March finding 70. Then 70 + 45 = 115. Find 115 in the table, observe the month at the top of column (April), then trace to the left-hand column finding 25. The date is April 25.

NOTE.—The above table applies to ordinary years of 365 days. For leap-year add one day to each number of days after February 28.

**Longitude.** The time required to make one complete revolution of the earth from meridian to meridian is not only divided into 24 hours, but it is also divided into 360 degrees. As the 24 hours and 360° are invariable, they bear a constant relation to each other; for example, $360 \div 24 = 15°$ of the great circle in one hour. Further, $\frac{15 \times 60}{60} = 15'$ of the great circle in 15 minutes of time, and lastly $\frac{15 \times 60}{60} = 15''$ of the great circle in 15 seconds of time. The east and west D.°, M.′, S.″, of the great circle are called degrees, minutes, and seconds of longitude. The hour, with its subdivisions of minutes and seconds, is reckoned as time.

## LONGITUDE AND TIME COMPARED

15° in longitude = 1 hour in time
15′ in longitude = 1 minute in time
15″ in longitude = 1 second in time
1° in longitude = 4 minutes in time
1′ in longitude = 4 seconds in time

$$1'' \text{ in longitude} = \frac{1}{15} = 0.667 \text{ in time}$$

Fractions of seconds are expressed decimally.

Longitude is reckoned along the equator from the first meridian. There is no natural starting-point for longitude as there is for *latitude;* the latter is reckoned from both sides of the equator to the north and south poles respectively. A quadrant of the earth's surface, or the distance from the equator to the pole, is divided into 90°, and again into minutes and seconds, and decimals of a second—of latitude.

Longitude must have an agreed starting-point; seafaring men have agreed upon, and commonly reckon, longitude east or west from Greenwich, England. Any other place would answer equally well, such as the longitude of Paris, or of Washington, but varying longitudes would result in endless confusion in the use of nautical tables, coast survey charts, etc.

A navigator's chief reliance is in the accuracy of the ship's chronometer as a time-piece which must correctly indicate Greenwich time, by which is meant that his chronometer must point to 12 o'clock when the sun is on the Greenwich meridian. Chronometers, like other trains of mechanism, are subject to variation, and the *rate,* whether fast or slow, must be carefully noted when computing daily observations. Suppose a ship going westward from Europe, and the noon observation to show a variation of 3 h., 36′ slower than the chronometer or Greenwich time, the position of the ship would be 54° west of Greenwich or within 20° of New York, for the difference in time between the two meridians is the difference in longitude.

## METRIC SYSTEM OF WEIGHTS AND MEASURES

### Bureau of Standards

**Fundamental Equivalents.** The fundamental unit of the metric system is the **meter**—the unit of length. From this the units of capacity (liter) and of weight (gram) were derived. All other units are the decimal subdivisions or multiples of these. These three units are simply related, *e.g.*, for all practical purposes one cubic decimeter equals one liter, and one liter of water weighs one kilogram. The metric tables are formed by combining the words " meter," " gram," and " liter " with six numerical prefixes as in the following tables:

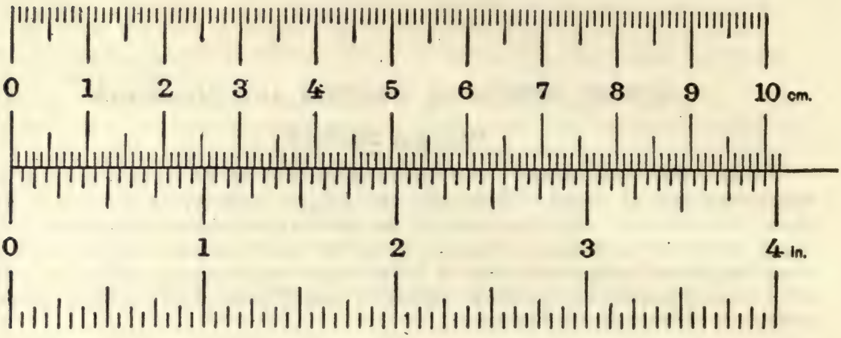
| Prefixes | Meaning | | | Units |
|---|---|---|---|---|
| Milli- | = one thousandth | $\frac{1}{1000}$ | .001 | |
| Centi- | = one hundredth | $\frac{1}{100}$ | .01 | Meter for length |
| Deci- | = one-tenth | $\frac{1}{10}$ | .1 | |
| Unit | = one | | 1. | Gram for weight or mass |
| Deka- | = ten | $\frac{10}{1}$ | 10 | |
| Hecto- | = one hundred | $\frac{100}{1}$ | 100 | Liter for capacity |
| Kilo- | = one thousand | $\frac{1000}{1}$ | 1000 | |

All lengths, areas, and cubic measures in the following tables are derived from the international meter, the legal equivalent being 1 meter = 39.37 inches (law of July 28, 1866). In 1893 the United States Office of Standard Weights and Measures was authorized to derive the yard from the meter, using for the purpose the relation legalized in 1866, 1 yard equals $\frac{3,600}{3,937}$ meter. The customary weights are likewise referred to the kilogram (Executive order approved April 5, 1893). This action fixed the values, inasmuch as the reference standards are as perfect and unalterable as it is possible for human skill to make them.

All capacities are based on the practical equivalent 1 cubic decimeter equals 1 liter. The decimeter is equal to 3.937 inches, in accordance with the legal equivalent of the meter given above. The gallon referred to in the tables is the United States gallon, 231 cubic inches. The bushel is the United States bushel of 2,150.42 cubic inches. These units must not be confused with the British units of the same name, which differ from those used in the United States. The British gallon is approximately 20 per cent larger and the British bushel 3 per cent larger than the corresponding units used in this country.

The customary weights derived from the international kilogram are based on the value 1 avoirdupois pound = 453.5924277 grams. This value is carried out further than that given in the law, but it is in accord with the latter as far as it is there given. The value of the troy pound is based upon the relations just mentioned, and also the equivalent $\frac{5,760}{7,000}$ avoirdupois pound equals 1 troy pound.

## Equivalents of Metric, United States, and British Measures




Comparison Scale: 10 Centimeters and 4 Inches. (Actual Size.)

### Lengths

| | | |
|---|---|---|
| 1 millimeter | 0.03937 | inch |
| 1 inch | 25.4001 | millimeters |
| 1 centimeter | 0.3937 | inch |
| 1 inch | 2.54001 | centimeters |
| 1 meter | 3.28083 | feet |
| 1 foot | 0.304801 | meter |
| 1 meter | 1.093611 | U. S. yards |
| 1 U. S. yard | 0.914402 | meter |
| 1 kilometer | 0.62137 | U. S. mile |
| 1 U. S. mile | 1.60935 | kilometers |

### Areas

| | | |
|---|---|---|
| 1 square millimeter | 0.00155 | square inch |
| 1 square inch | 645.16 | square millimeters |
| 1 square centimeter | 0.155 | square inch |
| 1 square inch | 6.452 | square centimeters |
| 1 square foot | 0.0929 | square meter |
| 1 square meter | 10.764 | square feet |
| 1 square yard | 0.8361 | square meter |
| 1 square meter | 1.196 | square yards |
| 1 square kilometer | 0.3861 | square mile |
| 1 square mile | 2.59 | square kilometers |
| 1 acre | 0.4047 | hectare |
| 1 hectare | 2.471 | acres |

### Volumes

| | | |
|---|---|---|
| 1 cubic millimeter | 0.000061 | cubic inch |
| 1 cubic inch | 16387.2 | cubic millimeters |
| 1 cubic centimeter | 0.061 | cubic inch |
| 1 cubic inch | 16.3872 | cubic centimeters |
| 1 cubic foot | 0.02832 | cubic meter |
| 1 cubic meter | 35.314 | cubic feet |
| 1 cubic yard | 0.7646 | cubic meter |
| 1 cubic meter | 1.3079 | cubic yards |

## Capacities

| | | |
|---|---|---|
| 1 milliliter (c.c.) | 0.03381 | U. S. liquid ounce |
| 1 U. S. liquid ounce | 29.574 | milliliters (c.c.) |
| 1 milliliter (c.c.) | 0.2705 | U. S. apothecary's dram |
| 1 apothecary's dram | 3.6967 | milliliters (c.c.) |
| 1 milliliter (c.c.) | 0.8115 | U. S. apothecary's scruple |
| 1 U. S. apothecary's scruple | 1.2322 | milliliters (c.c.) |
| 1 U. S. liquid quart | 0.94636 | liter |
| 1 Imperial quart | 1.1359 | liters |
| 1 liter | 1.05668 | U. S. liquid quarts |
| 1 liter | 0.8804 | Imperial quart |
| 1 liter | 0.26417 | U. S. liquid gallon |
| 1 liter | 0.2201 | Imperial gallon |
| 1 U. S. liquid gallon | 3.78543 | liters |
| 1 Imperial gallon | 4.5434 | liters |
| 1 liter | 0.9081 | U. S. dry quart |
| 1 U. S. dry quart | 1.1012 | liters |
| 1 liter | 0.11351 | U. S. peck |
| 1 U. S. peck | 8.8092 | liters |
| 1 U. S. peck | 0.881 | dekaliter |
| 1 dekaliter | 1.1351 | U. S. pecks |
| 1 U. S. bushel | 0.35239 | hectoliter |
| 1 hectoliter | 2.83774 | U. S. bushels |
| 1 hectoliter | 2.7512 | bushels (British) |
| 1 bushel (British) | 0.3635 | hectoliter |

## Volume, Area, and Length

| Metric Units | | U. S. and British Units |
|---|---|---|
| 1 cubic meter per lineal meter | 1.196 | cubic yards per lineal yard |
| 1 cubic yard per lineal yard | 0.836 | cubic meter per lineal meter |
| 1 cubic meter per square meter | 3.281 | cubic feet per square foot |
| 1 square foot per square foot | 3.048 | cubic meters per square meter |
| 1 liter per square meter | 0.0204 | Imperial gallon per square foot |
| 1 Imperial gallon per square foot | 48.905 | liters per square meter |
| 1 liter per square meter | 0.0245 | U. S. gallon per square foot |
| 1 U. S. gallon per square foot | 40.734 | liters per square meter |

## Weights and Volumes

| | | |
|---|---|---|
| 1 grain per Imperial gallon | 0.014 | gram per liter |
| 1 gram per liter | 70.116 | grains per Imperial gallon |
| 1 grain per U. S. gallon | 0.017 | gram per liter |
| 1 gram per liter | 58.386 | grains per U. S. gallon |
| 1 pound per Imperial gallon | 0.1 | kilogram per liter |
| 1 kilogram per liter | 10.017 | pounds per Imperial gallon |
| 1 pound per U. S. gallon | 0.1198 | kilogram per liter |
| 1 kilogram per liter | 8.345 | pounds per U. S. gallon |

## Weight

| | | |
|---|---|---|
| 1 grain | 0.0648 | gram |
| 1 gram | 15.4324 | grains |
| 1 avoirdupois ounce | 28.3495 | grams |
| 1 gram | 0.03527 | avoirdupois ounce |
| 1 troy ounce | 31.10348 | grams |
| 1 gram | 0.03215 | troy ounce |
| 1 avoirdupois pound | 0.45359 | kilogram |
| 1 kilogram | 2.20462 | avoirdupois pounds |

EQUIVALENTS OF METRIC, UNITED STATES, AND BRITISH MEASURES—(*Cont.*)

WEIGHT—(*Cont.*)

| | | |
|---|---|---|
| 1 troy pound | 0.37324 | kilogram |
| 1 kilogram | 2.67923 | troy pounds |
| 1 troy pound | 0.00037 | metric ton |
| 1 metric ton | 2679.23 | troy pounds |
| 1 avoirdupois pound | 0.00045 | metric ton |
| 1 metric ton | 2204.62 | avoirdupois pounds |
| 1 short ton | 0.90718 | metric ton |
| 1 short ton | 907.18 | kilograms |
| 1 long ton | 1.01605 | metric tons |
| 1 long ton | 1016.05 | kilograms |
| 1 metric ton | 0.98421 | long ton |

WEIGHTS AND MEASURES

| | | |
|---|---|---|
| 1 pound per cubic inch | 0.028 | kilogram per cubic centimeter |
| 1 kilogram per cubic centimeter | 36.25 | pounds per cubic inch |
| 1 pound per cubic foot | 16.02 | kilograms per cubic meter |
| 1 kilogram per cubic meter | 0.062 | pounds per cubic foot |
| 1 pound per cubic yard | 0.593 | kilogram per cubic meter |
| 1 kilogram per cubic meter | 1.685 | pounds per cubic yard |
| 1 short ton per cubic yard | 1.187 | metric tons per cubic meter |
| 1 metric ton per cubic meter | 0.843 | short tons per cubic yard |
| 1 long ton per cubic yard | 1.329 | metric tons per cubic meter |
| 1 metric ton per cubic meter | 0.752 | long ton per cubic yard |
| 1 cubic inch per pound | 36.125 | cubic centimeters per kilogram |
| 1 cubic centimeter per kilogram | 0.028 | cubic inch per pound |
| 1 cubic foot per pound | 0.062 | cubic meter per kilogram |
| 1 cubic meter per kilogram | 16.019 | cubic foot per pound |
| 1 cubic yard per pound | 1.685 | cubic meters per kilogram |
| 1 cubic meter per kilogram | 0.593 | cubic yard per pound |
| 1 cubic yard per short ton | 0.903 | cubic meters per metric ton |
| 1 cubic meter per metric ton | 1.107 | cubic yards per short ton |
| 1 cubic yard per long ton | 0.752 | cubic meters per metric ton |
| 1 cubic meter per metric ton | 1.329 | cubic yard per long ton |
| 1 cubic meter per metric ton | 29.879 | cubic feet per short ton |
| 1 cubic foot per short ton | 0.0335 | cubic meter per metric ton |
| 1 cubic meter per metric ton | 35.882 | cubic feet per long ton |
| 1 cubic foot per long ton | 0.0279 | cubic meter per metric ton |
| 1 pound per foot | 1.488 | kilograms per meter |
| 1 kilogram per meter | 0.672 | pound per foot |
| 1 pound per yard | 0.496 | kilogram per meter |
| 1 kilogram per meter | 2.016 | pounds per yard |
| 1 long ton per foot | 3333.333 | kilograms per meter |
| 1 kilogram per meter | 0.0003 | long ton per foot |
| 1 short ton per foot | 2775.666 | kilograms per meter |
| 1 kilogram per meter | 0.00036 | short tons per foot |
| 1 long ton per yard | 1.111 | metric tons per meter |
| 1 metric ton per meter | 0.9 | long tons per yard |
| 1 short ton per yard | 0.925 | metric tons per meter |
| 1 metric ton per meter | 1.081 | short tons per yard |
| 1 long ton per mile | 0.631 | metric tons per kilometer |
| 1 metric ton per kilometer | 1.584 | long tons per mile |
| 1 short ton per mile | 0.758 | metric tons per kilometer |
| 1 metric ton per kilometer | 1.319 | short tons per mile |

## Pressures

| | | |
|---|---|---|
| 1 pound per square inch | 0.0007 | kilogram per square millimeter |
| 1 kilogram per square millimeter | 1422.32 | pounds per square inch |
| 1 pound per square inch | 0.07 | kilogram per square centimeter |
| 1 kilogram per square centimeter | 14.223 | pounds per square inch |
| 1.0335 kilograms per square centimeter | 14.7 | pounds per sq. in. (1 atmosphere) |
| 14.7 pounds per sq. in. (1 atmosphere) | 0.07 | kilograms per square centimeter |
| 1 pound per square foot | 4.883 | kilograms per square meter |
| 1 kilogram per square meter | 0.205 | pounds per square foot |
| 1 short ton per square inch | 1.406 | kilograms per square millimeter |
| 1 kilogram per square millimeter | 0.711 | short ton per square inch |
| 1 long ton per square inch | 1.575 | kilograms per square millimeter |
| 1 kilogram per square millimeter | 0.635 | long tons per square inch |
| 1 short ton per square foot | 9.764 | metric ton per square meter |
| 1 metric ton per square meter | 0.102 | short ton per square foot |
| 1 long ton per square foot | 10.937 | metric tons per square meter |
| 1 metric ton per square meter | .0914 | long ton per square foot |
| 1 pound per square inch | 5.17 | centimeters of mercury |
| 1 centimeter of mercury | 0.193 | pound per square inch |
| 1 inch of mercury | 2.54 | centimeters of mercury |
| 1 centimeter of mercury | 0.394 | inch of mercury |

## Time, Velocity, Speed

| | | |
|---|---|---|
| 1 foot per second | 0.305 | meter per second |
| 1 meter per second | 3.281 | feet per second |
| 1 foot per minute | 0.305 | meter per minute |
| 1 meter per minute | 3.281 | feet per minute |
| 1 mile per hour | 1.609 | kilometers per hour |
| 1 kilometer per hour | 0.621 | mile per hour |
| 1 cubic foot per second | 0.0283 | cubic meter per second |
| 1 cubic meter per second | 35.316 | cubic feet per second |
| 1 cubic yard per minute | 0.765 | cubic meter per minute |
| 1 cubic meter per minute | 1.308 | cubic yard per minute |

## Work, Activity

| | | |
|---|---|---|
| 1 foot pound | 0.138 | kilogrammeter |
| 1 kilogrammeter | 7.233 | foot-pounds |
| 1 horsepower | 550.0 | foot-pounds per second |
| 1 foot-pound per second | 0.0018 | horsepower |
| 1 horsepower | 33000.0 | foot-pounds per minute |
| 1 foot-pound per minute | 0.00003 | horsepower |
| 1 horsepower | 76.0 | kilogrammeters per second |
| 1 kilogrammeter per second | 0.013 | horsepower |
| 1 horsepower | 1.014 | cheval |
| 1 cheval | 0.986 | horsepower |
| 1 horsepower | 0.746 | kilowatt |
| 1 kilowatt | 1.34 | horsepower |
| 1 cheval | 75.0 | kilogrammeters per second |
| 1 kilogrammeter per second | 0.013 | cheval |
| 1 cheval | 4500.0 | kilogrammeters per minute |
| 1 kilogrammeter per minute | 0.00022 | cheval |
| 1 cheval | 542.48 | foot-pounds per second |
| 1 foot-pound per second | 0.0018 | cheval |
| 1 pound per horsepower | 0.447 | kilogram per cheval |
| 1 kilogram per cheval | 2.235 | pounds per horsepower |
| 1 square foot per horsepower | 0.092 | square meter per cheval |

## Equivalents of Metric, United States, and British Measures—(*Cont.*)

### Work, Activity—(*Cont.*)

| | | |
|---|---|---|
| 1 square meter per cheval | 10.913 | square feet per horsepower |
| 1 cubic foot per horsepower | 0.028 | cubic meter per cheval |
| 1 cubic meter per cheval | 35.806 | cubic feet per horsepower |
| 1 foot-ton (2,240 pounds) | 0.31 | metric ton-meter |
| 1 metric ton-meter | 3.229 | foot-tons (2,240 pounds) |
| 1 foot-ton (2,000 pounds) | 0.276 | metric ton-meter |
| 1 metric ton-meter | 3.616 | foot-tons (2,000 pounds) |

### Heat

| | | |
|---|---|---|
| 1 unit of heat B.t.u. | 0.252 | calorie |
| 1 calorie | 3.968 | units of heat B.t.u. |
| 1 mechanical equivalent of heat (772 foot-pounds) | 10.67 | kilogrammeters |
| 1 kilogrammeter | 0.937 | mechanical equivalent of heat (772 foot-pounds) |
| 1 metric mechanical equivalent (425 kilogrammeters) | 3074.0 | foot-pounds = 774.7 foot-pounds per English unit |
| 1 heat unit per square foot | 2.713 | calories per square meter |
| 1 calorie per square meter | 0.369 | heat units per square foot |
| 1 heat unit per pound | 0.556 | calorie per kilogram |
| 1 calorie per kilogram | 1.8 | heat units per pound |

### Lengths. Fractions of an Inch to Millimeters

Reduction factor: 1 inch = 25.4001 millimeters

| Inch | | Milli-meters | Inch | | Milli-meters | Inch | | Milli-meters |
|---|---|---|---|---|---|---|---|---|
| Fraction | Decimal | | Fraction | Decimal | | Fraction | Decimal | |
| 1/64 | .015625 | .397 | 11/32 | .34375 | 8.731 | 43/64 | .671875 | 17.066 |
| 1/32 | .03125 | .794 | 23/64 | .359375 | 9.128 | 11/16 | .6875 | 17.463 |
| 3/64 | .046875 | 1.191 | 3/8 | .3750 | 9.525 | 45/64 | .703125 | 17.859 |
| 1/16 | .0625 | 1.588 | 25/64 | .390625 | 9.922 | 23/32 | .71875 | 18.256 |
| 5/64 | .078125 | 1.984 | 13/32 | .40625 | 10.319 | 47/64 | .734375 | 18.653 |
| 3/32 | .09375 | 2.381 | 27/64 | .421875 | 10.716 | 3/4 | .7500 | 19.050 |
| 7/64 | .109375 | 2.778 | 7/16 | .4375 | 11.113 | 49/64 | .765625 | 19.447 |
| 1/8 | .1250 | 3.175 | 29/64 | .453125 | 11.509 | 25/32 | .78125 | 19.844 |
| 9/64 | .140625 | 3.572 | 15/32 | .46875 | 11.906 | 51/64 | .796875 | 20.241 |
| 5/32 | .15625 | 3.969 | 31/64 | .484375 | 12.303 | 13/16 | .8125 | 20.638 |
| 11/64 | .171875 | 4.366 | 1/2 | .5000 | 12.700 | 53/64 | .828125 | 21.034 |
| 3/16 | .1875 | 4.763 | 33/64 | .515625 | 13.097 | 27/32 | .84375 | 21.431 |
| 13/64 | .203125 | 5.159 | 17/32 | .53125 | 13.494 | 55/64 | .859375 | 21.828 |
| 7/32 | .21875 | 5.556 | 35/64 | .546875 | 13.891 | 7/8 | .875 | 22.225 |
| 15/64 | .234375 | 5.953 | 9/16 | .5625 | 14.288 | 57/64 | .890625 | 22.622 |
| 1/4 | .2500 | 6.350 | 37/64 | .578125 | 14.684 | 29/32 | .90625 | 23.019 |
| 17/64 | .265625 | 6.747 | 19/32 | .59375 | 15.081 | 59/64 | .921875 | 23 416 |
| 9/32 | .28125 | 7.144 | 39/64 | .609375 | 15.478 | 15/16 | .9375 | 23.813 |
| 19/64 | .296875 | 7.541 | 5/8 | .625 | 15.875 | 61/64 | .953125 | 24.209 |
| 5/16 | .3125 | 7.938 | 41/64 | .640625 | 16.272 | 31/32 | .96875 | 24.606 |
| 21/64 | .328125 | 8.334 | 21/32 | .65625 | 16.669 | 63/64 | .984375 | 25.003 |
| | | | | | | 1 | 1.000 | 25.400 |

# INCHES AND FRACTIONS TO MILLIMETERS

## LENGTHS. INCHES AND FRACTIONS TO MILLIMETERS

Reduction factors: $\frac{1}{16}$ inch = 1.5875 millimeters
1 inch = 25.40 millimeters

| Inches | | Milli-meters | Inches | | Milli-meters | Inches | | Milli-meters |
|---|---|---|---|---|---|---|---|---|
| Fractions | Decimals | | Fractions | Decimals | | Fractions | Decimals | |
| 0 | 0 | 0 | $2\frac{1}{2}$ | 2.500 | 63.5 | 5 | ..... | 127.0 |
| $\frac{1}{16}$ | .0625 | 1.59 | $2\frac{9}{16}$ | 2.563 | 65.1 | $5\frac{1}{16}$ | 5.063 | 128.6 |
| $\frac{1}{8}$ | .125 | 3.18 | $2\frac{5}{8}$ | 2.625 | 66.7 | $5\frac{1}{8}$ | 5.125 | 130.2 |
| $\frac{3}{16}$ | .1875 | 4.76 | $2\frac{11}{16}$ | 2.688 | 68.3 | $5\frac{3}{16}$ | 5.188 | 131.8 |
| $\frac{1}{4}$ | .25 | 6.35 | $2\frac{3}{4}$ | 2.750 | 69.9 | $5\frac{1}{4}$ | 5.250 | 133.4 |
| $\frac{5}{16}$ | .3125 | 7.94 | $2\frac{13}{16}$ | 2.813 | 71.4 | $5\frac{5}{16}$ | 5.313 | 124.9 |
| $\frac{3}{8}$ | .375 | 9.53 | $2\frac{7}{8}$ | 2.875 | 73.0 | $5\frac{3}{8}$ | 5.375 | 136.5 |
| $\frac{7}{16}$ | .4375 | 11.11 | $2\frac{15}{16}$ | 2.938 | 74.6 | $5\frac{7}{16}$ | 5.438 | 138.1 |
| $\frac{1}{2}$ | .5 | 12.70 | 3 | ..... | 76.2 | $5\frac{1}{2}$ | 5.500 | 139.7 |
| $\frac{9}{16}$ | .5625 | 14.29 | $3\frac{1}{16}$ | 3.063 | 77.8 | $5\frac{9}{16}$ | 5.563 | 141.3 |
| $\frac{5}{8}$ | .625 | 15.88 | $3\frac{1}{8}$ | 3.125 | 79.4 | $5\frac{5}{8}$ | 5.625 | 142.9 |
| $\frac{11}{16}$ | .6875 | 17.46 | $3\frac{3}{16}$ | 3.188 | 81.0 | $5\frac{11}{16}$ | 5.688 | 144.5 |
| $\frac{3}{4}$ | .75 | 19.05 | $3\frac{1}{4}$ | 3.250 | 82.6 | $5\frac{3}{4}$ | 5.750 | 146.1 |
| $\frac{13}{16}$ | .8125 | 20.64 | $3\frac{5}{16}$ | 3.313 | 84.1 | $5\frac{13}{16}$ | 5.813 | 147.6 |
| $\frac{7}{8}$ | .875 | 22.23 | $3\frac{3}{8}$ | 3.375 | 85.7 | $5\frac{7}{8}$ | 5.875 | 149.2 |
| $\frac{15}{16}$ | .9375 | 23.81 | $3\frac{7}{16}$ | 3.438 | 87.3 | $5\frac{15}{16}$ | 5.938 | 150.8 |
| 1 | ..... | 25.4 | $3\frac{1}{2}$ | 3.500 | 88.9 | 6 | ..... | 152.4 |
| $1\frac{1}{16}$ | 1.063 | 27.0 | $3\frac{9}{16}$ | 3.563 | 90.5 | $6\frac{1}{16}$ | 6.063 | 154.0 |
| $1\frac{1}{8}$ | 1.125 | 28.6 | $3\frac{5}{8}$ | 3.625 | 92.1 | $6\frac{1}{8}$ | 6.125 | 155.6 |
| $1\frac{3}{16}$ | 1.188 | 30.2 | $3\frac{11}{16}$ | 3.688 | 93.7 | $6\frac{3}{16}$ | 6.188 | 157.2 |
| $1\frac{1}{4}$ | 1.250 | 31.8 | $3\frac{3}{4}$ | 3.750 | 95.3 | $6\frac{1}{4}$ | 6.250 | 158.8 |
| $1\frac{5}{16}$ | 1.313 | 33.3 | $3\frac{13}{16}$ | 3.813 | 96.8 | $6\frac{5}{16}$ | 6.313 | 160.3 |
| $1\frac{3}{8}$ | 1.375 | 34.9 | $3\frac{7}{8}$ | 3.875 | 98.4 | $6\frac{3}{8}$ | 6.375 | 161.9 |
| $1\frac{7}{16}$ | 1.438 | 36.5 | $3\frac{15}{16}$ | 3.938 | 100.0 | $6\frac{7}{16}$ | 6.438 | 163.5 |
| $1\frac{1}{2}$ | 1.500 | 38.1 | 4 | ..... | 101.6 | $6\frac{1}{2}$ | 6.500 | 165.1 |
| $1\frac{9}{16}$ | 1.563 | 39.7 | $4\frac{1}{16}$ | 4.063 | 103.2 | $6\frac{9}{16}$ | 6.563 | 166.7 |
| $1\frac{5}{8}$ | 1.625 | 41.3 | $4\frac{1}{8}$ | 4.125 | 104.8 | $6\frac{5}{8}$ | 6.625 | 168.3 |
| $1\frac{11}{16}$ | 1.688 | 42.9 | $4\frac{3}{16}$ | 4.188 | 106.4 | ... | ..... | ..... |
| $1\frac{3}{4}$ | 1.750 | 44.5 | $4\frac{1}{4}$ | 4.250 | 108.0 | $6\frac{11}{16}$ | 6.688 | 169.9 |
| $1\frac{13}{16}$ | 1.813 | 46.0 | $4\frac{5}{16}$ | 4.313 | 109.5 | $6\frac{3}{4}$ | 6.750 | 171.5 |
| $1\frac{7}{8}$ | 1.875 | 47.6 | $4\frac{3}{8}$ | 4.375 | 111.1 | $6\frac{13}{16}$ | 6.813 | 173.0 |
| $1\frac{15}{16}$ | 1.938 | 49.2 | $4\frac{7}{16}$ | 4.438 | 112.7 | $6\frac{7}{8}$ | 6.875 | 174.6 |
| 2 | ..... | 50.8 | $4\frac{1}{2}$ | 4.500 | 114.3 | $6\frac{15}{16}$ | 6.938 | 176.2 |
| $2\frac{1}{16}$ | 2.063 | 52.4 | $4\frac{9}{16}$ | 4.563 | 115.9 | 7 | ..... | 177.8 |
| $2\frac{1}{8}$ | 2.125 | 54.0 | $4\frac{5}{8}$ | 4.625 | 117.5 | $7\frac{1}{16}$ | 7.063 | 179.4 |
| $2\frac{3}{16}$ | 2.188 | 55.6 | $4\frac{11}{16}$ | 4.688 | 119.1 | $7\frac{1}{8}$ | 7.125 | 181.0 |
| $2\frac{1}{4}$ | 2.250 | 57.2 | $4\frac{3}{4}$ | 4.750 | 120.7 | $7\frac{3}{16}$ | 7.188 | 182.6 |
| $2\frac{5}{16}$ | 2.313 | 58.7 | $4\frac{13}{16}$ | 4.813 | 122.2 | $7\frac{1}{4}$ | 7.250 | 184.2 |
| $2\frac{3}{8}$ | 2.375 | 60.3 | $4\frac{7}{8}$ | 4.875 | 123.8 | $7\frac{5}{16}$ | 7.313 | 185.7 |
| $2\frac{7}{16}$ | 2.438 | 61.9 | $4\frac{15}{16}$ | 4.938 | 125.4 | $7\frac{3}{8}$ | 7.375 | 187.3 |

LENGTHS. INCHES AND FRACTIONS TO MILLIMETERS—(*Cont.*)

| Inches | | Milli-meters | Inches | | Milli-meters | Inches | | Milli-meters |
|---|---|---|---|---|---|---|---|---|
| Fractions | Decimals | | Fractions | Decimals | | Fractions | Decimals | |
| $7\frac{7}{16}$ | 7.438 | 188.9 | $10\frac{1}{4}$ | 10.250 | 260.4 | $13\frac{1}{16}$ | 13.063 | 331.8 |
| $7\frac{1}{2}$ | 7.500 | 190.5 | $10\frac{5}{16}$ | 10.313 | 261.9 | $13\frac{1}{8}$ | 13.125 | 333.4 |
| $7\frac{9}{16}$ | 7.563 | 192.1 | $10\frac{3}{8}$ | 10.375 | 263.5 | $13\frac{3}{16}$ | 13.188 | 335.0 |
| $7\frac{5}{8}$ | 7.625 | 193.7 | $10\frac{7}{16}$ | 10.438 | 265.1 | $13\frac{1}{4}$ | 13.250 | 336.6 |
| $7\frac{11}{16}$ | 7.688 | 195.3 | $10\frac{1}{2}$ | 10.500 | 266.7 | $13\frac{5}{16}$ | 13.313 | 338.1 |
| $7\frac{3}{4}$ | 7.750 | 196.9 | $10\frac{9}{16}$ | 10.563 | 268.3 | $13\frac{3}{8}$ | 13.375 | 339.7 |
| $7\frac{13}{16}$ | 7.813 | 198.4 | $10\frac{5}{8}$ | 10.625 | 269.9 | $13\frac{7}{16}$ | 13.438 | 341.3 |
| $7\frac{7}{8}$ | 7.875 | 200.0 | $10\frac{11}{16}$ | 10.688 | 271.5 | $13\frac{1}{2}$ | 13.500 | 342.9 |
| $7\frac{15}{16}$ | 7.938 | 201.6 | $10\frac{3}{4}$ | 10.750 | 273.1 | $13\frac{9}{16}$ | 13.563 | 344.5 |
| 8 | ..... | 203.2 | $10\frac{13}{16}$ | 10.813 | 274.6 | $13\frac{5}{8}$ | 13.625 | 346.1 |
| $8\frac{1}{16}$ | 8.063 | 204.8 | $10\frac{7}{8}$ | 10.875 | 276.2 | $13\frac{11}{16}$ | 13.688 | 347.7 |
| $8\frac{1}{8}$ | 8.125 | 206.4 | $10\frac{15}{16}$ | 10.938 | 277.8 | $13\frac{3}{4}$ | 13.750 | 349.3 |
| $8\frac{3}{16}$ | 8.188 | 208.0 | 11 | ...... | 279.4 | $13\frac{13}{16}$ | 13.813 | 350.8 |
| $8\frac{1}{4}$ | 8.250 | 209.6 | $11\frac{1}{16}$ | 11.063 | 281.0 | $13\frac{7}{8}$ | 13.875 | 352.4 |
| $8\frac{5}{16}$ | 8.313 | 211.1 | $11\frac{1}{8}$ | 11.125 | 282.6 | $13\frac{15}{16}$ | 13.938 | 354.0 |
| $8\frac{3}{8}$ | 8.375 | 212.7 | $11\frac{3}{16}$ | 11.188 | 285.2 | 14 | ...... | 355.6 |
| $8\frac{7}{16}$ | 8.438 | 214.3 | $11\frac{1}{4}$ | 11.250 | 285.8 | $14\frac{1}{16}$ | 14.063 | 357.2 |
| $8\frac{1}{2}$ | 8.500 | 215.9 | $11\frac{5}{16}$ | 11.313 | 287.3 | $14\frac{1}{8}$ | 14.125 | 358.8 |
| $8\frac{9}{16}$ | 8.563 | 217.5 | $11\frac{3}{8}$ | 11.375 | 288.9 | $14\frac{3}{16}$ | 14.188 | 360.4 |
| $8\frac{5}{8}$ | 8.625 | 219.1 | $11\frac{7}{16}$ | 11.438 | 290.5 | $14\frac{1}{4}$ | 14.250 | 362.0 |
| $8\frac{11}{16}$ | 8.688 | 220.7 | $11\frac{1}{2}$ | 11.500 | 292.1 | $14\frac{5}{16}$ | 14.313 | 363.5 |
| $8\frac{3}{4}$ | 8.750 | 222.3 | $11\frac{9}{16}$ | 11.563 | 293.7 | $14\frac{3}{8}$ | 14.375 | 365.1 |
| $8\frac{13}{16}$ | 8.813 | 223.8 | $11\frac{5}{8}$ | 11.625 | 295.3 | $14\frac{7}{16}$ | 14.438 | 366.7 |
| $8\frac{7}{8}$ | 8.875 | 225.4 | $11\frac{11}{16}$ | 11.688 | 296.9 | $14\frac{1}{2}$ | 14.500 | 368.3 |
| $8\frac{15}{16}$ | 8.938 | 227.0 | $11\frac{3}{4}$ | 11.750 | 298.5 | $14\frac{9}{16}$ | 14.563 | 369.9 |
| 9 | ..... | 228.6 | $11\frac{13}{16}$ | 11.813 | 300.0 | $14\frac{5}{8}$ | 14.625 | 371.5 |
| $9\frac{1}{16}$ | 9.063 | 230.2 | $11\frac{7}{8}$ | 11.875 | 301.6 | $14\frac{11}{16}$ | 14.688 | 373.1 |
| $9\frac{1}{8}$ | 9.125 | 231.8 | $11\frac{15}{16}$ | 11.938 | 303.2 | $14\frac{3}{4}$ | 14.750 | 374.7 |
| $9\frac{3}{16}$ | 9.188 | 233.4 | 12 | ...... | 304.8 | $14\frac{13}{16}$ | 14.813 | 376.2 |
| $9\frac{1}{4}$ | 9.250 | 235.0 | $12\frac{1}{16}$ | 12.063 | 306.4 | $14\frac{7}{8}$ | 14.875 | 377.8 |
| $9\frac{5}{16}$ | 9.313 | 236.5 | $12\frac{1}{8}$ | 12.125 | 308.0 | $14\frac{15}{16}$ | 14.938 | 379.4 |
| $9\frac{3}{8}$ | 9.375 | 238.1 | $12\frac{3}{16}$ | 12.188 | 309.6 | 15 | ...... | 381.0 |
| $9\frac{7}{16}$ | 9.438 | 239.7 | $12\frac{1}{4}$ | 12.250 | 311.2 | $15\frac{1}{16}$ | 16.063 | 382.6 |
| $9\frac{1}{2}$ | 9.500 | 241.3 | $12\frac{5}{16}$ | 12.313 | 312.7 | $15\frac{1}{8}$ | 15.125 | 384.2 |
| $9\frac{9}{16}$ | 9.563 | 242.9 | $12\frac{3}{8}$ | 12.375 | 314.3 | $15\frac{3}{16}$ | 15.188 | 385.8 |
| $9\frac{5}{8}$ | 9.625 | 244.5 | $12\frac{7}{16}$ | 12.438 | 315.9 | $15\frac{1}{4}$ | 15.250 | 387.4 |
| $9\frac{11}{16}$ | 9.688 | 246.1 | $12\frac{1}{2}$ | 12.500 | 317.5 | $15\frac{5}{16}$ | 15.313 | 388.9 |
| $9\frac{3}{4}$ | 9.750 | 247.7 | $12\frac{9}{16}$ | 12.563 | 319.1 | $15\frac{3}{8}$ | 15.375 | 390.5 |
| $9\frac{13}{16}$ | 9.813 | 249.2 | $12\frac{5}{8}$ | 12.625 | 320.7 | $15\frac{7}{16}$ | 15.438 | 392.1 |
| $9\frac{7}{8}$ | 9.875 | 250.8 | $12\frac{11}{16}$ | 12.688 | 322.3 | $15\frac{1}{2}$ | 15.500 | 393.7 |
| $9\frac{15}{16}$ | 9.938 | 252.4 | $12\frac{3}{4}$ | 12.750 | 323.9 | $15\frac{9}{16}$ | 15.563 | 395.3 |
| 10 | ..... | 254.0 | $12\frac{13}{16}$ | 12.813 | 325.4 | $15\frac{5}{8}$ | 15.625 | 396.9 |
| $10\frac{1}{16}$ | 10.063 | 255.6 | $12\frac{7}{8}$ | 12.875 | 327.0 | $15\frac{11}{16}$ | 15.688 | 398.5 |
| $10\frac{1}{8}$ | 10.125 | 257.2 | $12\frac{15}{16}$ | 12.938 | 328.6 | $15\frac{3}{4}$ | 15.750 | 400.0 |
| $10\frac{3}{16}$ | 10.188 | 258.8 | 13 | ...... | 330.2 | $15\frac{13}{16}$ | 15.813 | 401.6 |

LENGTHS. INCHES AND FRACTIONS TO MILLIMETERS—(*Cont.*)

| Inches | | Milli-meters | Inches | | Milli-meters | Inches | | Milli-meters |
|---|---|---|---|---|---|---|---|---|
| Fractions | Decimals | | Fractions | Decimals | | Fractions | Decimals | |
| $15\frac{7}{8}$ | 15.875 | 403.2 | $18\frac{11}{16}$ | 18.688 | 474.7 | $21\frac{7}{16}$ | 21.438 | 544.5 |
| $15\frac{15}{16}$ | 15.938 | 404.8 | $18\frac{3}{4}$ | 18.750 | 476.3 | $21\frac{1}{2}$ | 21.500 | 546.1 |
| 16 | ...... | 406.4 | $18\frac{13}{16}$ | 18.813 | 477.8 | $21\frac{9}{16}$ | 21.563 | 447.7 |
| $16\frac{1}{16}$ | 16.063 | 408.0 | $18\frac{7}{8}$ | 18.875 | 479.4 | $21\frac{5}{8}$ | 21.625 | 549.3 |
| $16\frac{1}{8}$ | 16.125 | 409.6 | $18\frac{15}{16}$ | 18.938 | 481.0 | $21\frac{11}{16}$ | 21.688 | 550.9 |
| $16\frac{3}{16}$ | 16.188 | 411.2 | 19 | ...... | 482.6 | $21\frac{3}{4}$ | 21.750 | 552.5 |
| $16\frac{1}{4}$ | 16.250 | 412.8 | $19\frac{1}{16}$ | 19.063 | 484.2 | $21\frac{13}{16}$ | 21.813 | 554.0 |
| $16\frac{5}{16}$ | 16.313 | 414.3 | $19\frac{1}{8}$ | 19.125 | 485.8 | $21\frac{7}{8}$ | 21.875 | 555.6 |
| $16\frac{3}{8}$ | 16.375 | 415.9 | $19\frac{3}{16}$ | 19.188 | 487.4 | $21\frac{15}{16}$ | 21.938 | 557.2 |
| $16\frac{7}{8}$ | 16.438 | 417.5 | $19\frac{1}{4}$ | 19.250 | 489.0 | 22 | ...... | 558.8 |
| $16\frac{1}{2}$ | 16.500 | 419.1 | $19\frac{5}{16}$ | 19.313 | 490.5 | $22\frac{1}{16}$ | 22.063 | 560.4 |
| $16\frac{9}{16}$ | 16.563 | 420.7 | $19\frac{3}{8}$ | 19.375 | 492.1 | $22\frac{1}{8}$ | 22.125 | 562.0 |
| $16\frac{5}{8}$ | 16.625 | 422.3 | $19\frac{7}{16}$ | 19.438 | 493.7 | $22\frac{3}{16}$ | 22.188 | 563.6 |
| $16\frac{11}{16}$ | 16.688 | 423.9 | $19\frac{1}{2}$ | 19.500 | 495.3 | $22\frac{1}{4}$ | 22.250 | 565.2 |
| $16\frac{3}{4}$ | 16.750 | 425.5 | $19\frac{9}{16}$ | 19.563 | 496.9 | $22\frac{5}{16}$ | 22.313 | 566.7 |
| $16\frac{13}{16}$ | 16.813 | 427.0 | $19\frac{5}{8}$ | 19.625 | 498.5 | $22\frac{3}{8}$ | 22.375 | 568.3 |
| $16\frac{7}{8}$ | 16.875 | 428.6 | $19\frac{11}{16}$ | 19.688 | 500.1 | $22\frac{7}{16}$ | 22.438 | 569.9 |
| $16\frac{15}{16}$ | 16.938 | 430.2 | $19\frac{3}{4}$ | 19.750 | 501.7 | $22\frac{1}{2}$ | 22.500 | 571.5 |
| 17 | ...... | 431.8 | $19\frac{13}{16}$ | 19.813 | 503.2 | $22\frac{9}{16}$ | 22.563 | 573.1 |
| $17\frac{1}{16}$ | 17.063 | 433.4 | $19\frac{7}{8}$ | 19.875 | 404.8 | $22\frac{5}{8}$ | 22.625 | 574.7 |
| $17\frac{1}{8}$ | 17.125 | 435.0 | $19\frac{15}{16}$ | 19.938 | 506.4 | $22\frac{11}{16}$ | 22.688 | 576.3 |
| $17\frac{3}{16}$ | 17.188 | 436.6 | 20 | ...... | 508.0 | $22\frac{3}{4}$ | 22.750 | 577.9 |
| $17\frac{1}{4}$ | 17.250 | 438.2 | $20\frac{1}{16}$ | 20.063 | 509.6 | $22\frac{13}{16}$ | 22.813 | 579.4 |
| $17\frac{5}{16}$ | 17.313 | 439.7 | $20\frac{1}{8}$ | 20.125 | 511.2 | $22\frac{7}{8}$ | 22.875 | 581.0 |
| $17\frac{3}{8}$ | 17.375 | 441.3 | $20\frac{3}{16}$ | 20.188 | 512.8 | $22\frac{15}{16}$ | 22.938 | 582.6 |
| $17\frac{7}{16}$ | 17.438 | 442.9 | $20\frac{1}{4}$ | 20.250 | 514.4 | 23 | ...... | 584.2 |
| $17\frac{1}{2}$ | 17.500 | 444.5 | $20\frac{5}{16}$ | 20.313 | 515.9 | $23\frac{1}{16}$ | 23.063 | 585.8 |
| $17\frac{9}{16}$ | 17.563 | 446.1 | $20\frac{3}{8}$ | 20.375 | 517.5 | $23\frac{1}{8}$ | 23.125 | 587.4 |
| $17\frac{5}{8}$ | 17.625 | 447.7 | $20\frac{7}{16}$ | 20.438 | 519.1 | $23\frac{3}{16}$ | 23.188 | 589.0 |
| $17\frac{11}{16}$ | 17.688 | 449.3 | .... | ...... | ..... | $23\frac{1}{4}$ | 23.250 | 590.6 |
| $17\frac{3}{4}$ | 17.750 | 450.9 | $20\frac{1}{2}$ | 20.500 | 520.7 | $23\frac{5}{16}$ | 23.313 | 592.1 |
| $17\frac{13}{16}$ | 17.813 | 452.4 | $20\frac{9}{16}$ | 20.563 | 522.3 | $23\frac{3}{8}$ | 23.375 | 593.7 |
| $17\frac{7}{8}$ | 17.875 | 454.0 | $20\frac{5}{8}$ | 20.625 | 523.9 | $23\frac{7}{16}$ | 23.438 | 595.3 |
| $17\frac{15}{16}$ | 17.938 | 455.6 | $20\frac{11}{16}$ | 20.688 | 525.5 | $23\frac{1}{2}$ | 23.500 | 596.9 |
| 18 | ...... | 457.2 | $20\frac{3}{4}$ | 20.750 | 527.1 | $23\frac{9}{16}$ | 23.563 | 598.5 |
| $18\frac{1}{16}$ | 18.063 | 458.8 | $20\frac{13}{16}$ | 20.813 | 528.6 | $23\frac{5}{8}$ | 23.625 | 600.1 |
| $18\frac{1}{8}$ | 18.125 | 460.4 | $20\frac{7}{8}$ | 20.875 | 530.2 | $23\frac{11}{16}$ | 23.688 | 601.7 |
| $18\frac{3}{16}$ | 18.188 | 462.0 | $20\frac{15}{16}$ | 20.938 | 531.8 | $23\frac{3}{4}$ | 23.750 | 603.3 |
| $18\frac{1}{4}$ | 18.250 | 463.6 | 21 | ...... | 533.4 | $23\frac{13}{16}$ | 23.813 | 604.8 |
| $18\frac{5}{16}$ | 18.313 | 465.1 | $21\frac{1}{16}$ | 21.063 | 535.0 | $23\frac{7}{8}$ | 23.875 | 606.4 |
| $18\frac{3}{8}$ | 18.375 | 466.7 | $21\frac{1}{8}$ | 21.125 | 536.6 | $23\frac{15}{16}$ | 23.938 | 608.0 |
| $18\frac{7}{16}$ | 18.438 | 468.3 | $21\frac{3}{16}$ | 21.188 | 538.2 | 24 | ...... | 609.6 |
| $18\frac{1}{2}$ | 18.500 | 469.9 | $21\frac{1}{4}$ | 21.250 | 539.8 | $24\frac{1}{16}$ | 24.063 | 611.2 |
| $18\frac{9}{16}$ | 18.563 | 471.5 | $21\frac{5}{16}$ | 21.313 | 541.3 | $24\frac{1}{8}$ | 24.125 | 612.8 |
| $18\frac{5}{8}$ | 18.625 | 473.1 | $21\frac{3}{8}$ | 21.375 | 542.9 | $24\frac{3}{16}$ | 24.188 | 614.4 |

LENGTHS. INCHES AND FRACTIONS TO MILLIMETERS—(*Cont.*)

| Inches | | Milli-meters | Inches | | Milli-meters | Inches | | Milli-meters |
|---|---|---|---|---|---|---|---|---|
| Fractions | Decimals | | Fractions | Decimals | | Fractions | Decimals | |
| $24\frac{1}{4}$ | 24.250 | 616.0 | $27\frac{1}{16}$ | 27.063 | 687.4 | $29\frac{7}{8}$ | 29.875 | 758.8 |
| $24\frac{5}{16}$ | 24.313 | 617.5 | $27\frac{1}{8}$ | 27.125 | 689.0 | $29\frac{15}{16}$ | 29.938 | 760.4 |
| $24\frac{3}{8}$ | 24.375 | 619.1 | $27\frac{3}{16}$ | 27.188 | 690.6 | 30 | ...... | 762.0 |
| $24\frac{7}{16}$ | 24.438 | 620.7 | $27\frac{1}{4}$ | 27.250 | 692.2 | $30\frac{1}{16}$ | 30.063 | 763.6 |
| $24\frac{1}{2}$ | 24.500 | 622.3 | $27\frac{5}{16}$ | 27.313 | 693.7 | $30\frac{1}{8}$ | 30.125 | 765.2 |
| $24\frac{9}{16}$ | 24.563 | 623.9 | $27\frac{3}{8}$ | 27.375 | 695.3 | $30\frac{3}{16}$ | 30.188 | 766.8 |
| $24\frac{5}{8}$ | 24.625 | 625.5 | $27\frac{7}{16}$ | 27.438 | 696.9 | $30\frac{1}{4}$ | 30.250 | 768.4 |
| $24\frac{11}{16}$ | 24.688 | 627.1 | $27\frac{1}{2}$ | 27.500 | 698.5 | $30\frac{5}{16}$ | 30.313 | 769.9 |
| $24\frac{3}{4}$ | 24.750 | 628.7 | $27\frac{9}{16}$ | 27.563 | 700.1 | $30\frac{3}{8}$ | 30.375 | 771.5 |
| $24\frac{13}{16}$ | 24.813 | 630.2 | $27\frac{5}{8}$ | 27.625 | 701.7 | $30\frac{7}{16}$ | 30.438 | 773.1 |
| $34\frac{7}{8}$ | 24.875 | 631.8 | $27\frac{11}{16}$ | 27.678 | 703.3 | $30\frac{1}{2}$ | 30.500 | 774.7 |
| $24\frac{15}{16}$ | 24.938 | 633.4 | $27\frac{3}{4}$ | 27.750 | 704.9 | $30\frac{9}{16}$ | 30.563 | 776.3 |
| 25 | ...... | 635.0 | $27\frac{13}{16}$ | 27.813 | 706.4 | $30\frac{5}{8}$ | 30.625 | 777.9 |
| $25\frac{1}{16}$ | 25.063 | 636.6 | $27\frac{7}{8}$ | 27.875 | 708.0 | $30\frac{11}{16}$ | 30.688 | 779.5 |
| $25\frac{1}{8}$ | 25.125 | 638.2 | $27\frac{15}{16}$ | 27.938 | 709.6 | $30\frac{3}{4}$ | 30.750 | 781.1 |
| $25\frac{3}{16}$ | 25.188 | 639.8 | 28 | ...... | 711.2 | $30\frac{13}{16}$ | 30.813 | 782.6 |
| $25\frac{1}{4}$ | 25.250 | 641.4 | $28\frac{1}{16}$ | 28.063 | 712.8 | $30\frac{7}{8}$ | 30.875 | 784.2 |
| $25\frac{5}{16}$ | 25.313 | 642.9 | $28\frac{1}{8}$ | 28.125 | 714.4 | $30\frac{15}{16}$ | 30.938 | 785.8 |
| $25\frac{3}{8}$ | 25.375 | 644.5 | $28\frac{3}{16}$ | 28.188 | 716.0 | 31 | ...... | 787.4 |
| $25\frac{7}{16}$ | 25.438 | 646.1 | $28\frac{1}{4}$ | 28.250 | 717.6 | $31\frac{1}{16}$ | 31.063 | 789.0 |
| $25\frac{1}{2}$ | 25.500 | 647.7 | $28\frac{5}{16}$ | 28.313 | 719.1 | $31\frac{1}{8}$ | 31.125 | 790.6 |
| $25\frac{9}{16}$ | 25.563 | 649.3 | $28\frac{3}{8}$ | 28.375 | 720.7 | $31\frac{3}{16}$ | 31.188 | 792.2 |
| $25\frac{5}{8}$ | 25.625 | 650.9 | $28\frac{7}{16}$ | 28.438 | 722.3 | $31\frac{1}{4}$ | 31.250 | 793.8 |
| $25\frac{11}{16}$ | 25.688 | 652.5 | $28\frac{1}{2}$ | 28.500 | 723.9 | $31\frac{5}{16}$ | 31.313 | 795.3 |
| $25\frac{3}{4}$ | 25.750 | 654.1 | $28\frac{9}{16}$ | 28.563 | 725.5 | $31\frac{3}{8}$ | 31.375 | 796.9 |
| $25\frac{13}{16}$ | 25.813 | 655.5 | $28\frac{5}{8}$ | 28.625 | 727.1 | $31\frac{7}{16}$ | 31.438 | 798.5 |
| $25\frac{7}{8}$ | 25.875 | 657.2 | $28\frac{11}{16}$ | 28.688 | 728.7 | $31\frac{1}{2}$ | 31.500 | 800.1 |
| $25\frac{15}{16}$ | 25.938 | 658.8 | $28\frac{3}{4}$ | 28.750 | 730.3 | $31\frac{9}{16}$ | 31.563 | 801.7 |
| 26 | ...... | 660.4 | $28\frac{13}{16}$ | 28.813 | 731.8 | $31\frac{5}{8}$ | 31.625 | 803.3 |
| $26\frac{1}{16}$ | 26.063 | 662.0 | $28\frac{7}{8}$ | 28.875 | 733.4 | $31\frac{11}{16}$ | 31.688 | 804.9 |
| $26\frac{1}{8}$ | 26.125 | 663.6 | $28\frac{15}{16}$ | 28.938 | 735.0 | $31\frac{3}{4}$ | 31.750 | 806.5 |
| $26\frac{3}{16}$ | 26.188 | 665.2 | 29 | ...... | 736.6 | $31\frac{13}{16}$ | 31.813 | 808.0 |
| $26\frac{1}{4}$ | 26.250 | 666.8 | $29\frac{1}{16}$ | 29.063 | 738.2 | $31\frac{7}{8}$ | 31.875 | 809.6 |
| $26\frac{5}{16}$ | 26.313 | 668.3 | $29\frac{1}{8}$ | 29.125 | 739.8 | $31\frac{15}{16}$ | 31.938 | 811.2 |
| $26\frac{3}{8}$ | 26.375 | 669.9 | $29\frac{3}{16}$ | 29.188 | 741.4 | 32 | ...... | 812.8 |
| $26\frac{7}{16}$ | 26.438 | 671.5 | $29\frac{1}{4}$ | 29.250 | 743.0 | $32\frac{1}{16}$ | 32.063 | 814.4 |
| $26\frac{1}{2}$ | 26.500 | 673.1 | $29\frac{5}{16}$ | 29.313 | 744.5 | $32\frac{1}{8}$ | 32.125 | 816.0 |
| $26\frac{9}{16}$ | 26.563 | 674.7 | $29\frac{3}{8}$ | 29.375 | 746.1 | $32\frac{3}{16}$ | 32.188 | 817.6 |
| $26\frac{5}{8}$ | 26.625 | 676.3 | $29\frac{7}{16}$ | 29.438 | 747.7 | $32\frac{1}{4}$ | 32.250 | 819.2 |
| $26\frac{11}{16}$ | 26.688 | 677.9 | $29\frac{1}{2}$ | 29.500 | 749.3 | $32\frac{5}{16}$ | 32.313 | 820.7 |
| $26\frac{3}{4}$ | 26.750 | 679.5 | $29\frac{9}{16}$ | 29.563 | 750.9 | $32\frac{3}{8}$ | 32.375 | 822.3 |
| $26\frac{13}{16}$ | 26.813 | 681.0 | $29\frac{5}{8}$ | 29.625 | 752.5 | $32\frac{7}{16}$ | 32.438 | 823.9 |
| $26\frac{7}{8}$ | 26.875 | 682.6 | $29\frac{11}{16}$ | 29.688 | 754.1 | $32\frac{1}{2}$ | 32.500 | 825.5 |
| $26\frac{15}{16}$ | 26.938 | 684.2 | $29\frac{3}{4}$ | 29.750 | 755.7 | $32\frac{9}{16}$ | 32.563 | 827.1 |
| 27 | ...... | 685.8 | $29\frac{13}{16}$ | 29.813 | 757.2 | $32\frac{5}{8}$ | 32.625 | 828.7 |

LENGTHS. INCHES AND FRACTIONS TO MILLIMETERS—(*Cont.*)

| Inches | | Millimeters | Inches | | Millimeters | Inches | | Millimeters |
|---|---|---|---|---|---|---|---|---|
| Fractions | Decimals | | Fractions | Decimals | | Fractions | Decimals | |
| $32\frac{11}{16}$ | 32.688 | 830.3 | $35\frac{3}{16}$ | 35.188 | 893.8 | $37\frac{11}{16}$ | 37.688 | 957.3 |
| $32\frac{3}{4}$ | 32.750 | 831.9 | $35\frac{1}{4}$ | 35.250 | 895.4 | $37\frac{3}{4}$ | 37.750 | 958.9 |
| $32\frac{13}{16}$ | 32.813 | 833.4 | $35\frac{5}{16}$ | 35.313 | 896.9 | $37\frac{13}{16}$ | 37.813 | 960.4 |
| $32\frac{7}{8}$ | 32.875 | 835.0 | $35\frac{3}{8}$ | 35.375 | 898.5 | $37\frac{7}{8}$ | 37.875 | 962.0 |
| $32\frac{15}{16}$ | 32.938 | 836.6 | $35\frac{7}{16}$ | 35.438 | 900.1 | $37\frac{15}{16}$ | 37.938 | 963.6 |
| 33 | ...... | 838.2 | $35\frac{1}{2}$ | 35.500 | 901.7 | 38 | ...... | 965.2 |
| $33\frac{1}{16}$ | 33.063 | 839.8 | $35\frac{9}{16}$ | 35.563 | 903.3 | $38\frac{1}{16}$ | 38.063 | 966.8 |
| $33\frac{1}{8}$ | 33.125 | 841.4 | $35\frac{5}{8}$ | 35.625 | 904.9 | $38\frac{1}{8}$ | 38.125 | 968.4 |
| $33\frac{3}{16}$ | 33.188 | 843.0 | $35\frac{11}{16}$ | 35.688 | 906.5 | $38\frac{3}{16}$ | 38.188 | 790.0 |
| $33\frac{1}{4}$ | 33.250 | 844.5 | $35\frac{3}{4}$ | 35.750 | 908.1 | $38\frac{1}{4}$ | 38.250 | 971.6 |
| $33\frac{5}{16}$ | 33.313 | 846.1 | $35\frac{13}{16}$ | 35.813 | 909.6 | $38\frac{5}{16}$ | 38.313 | 973.1 |
| $33\frac{3}{8}$ | 33.375 | 847.7 | $35\frac{7}{8}$ | 35.875 | 911.2 | $38\frac{3}{8}$ | 38.375 | 974.7 |
| $33\frac{7}{16}$ | 33.438 | 849.3 | $35\frac{15}{16}$ | 35.938 | 912.8 | $38\frac{7}{16}$ | 38.438 | 976.3 |
| $33\frac{1}{2}$ | 33.500 | 850.9 | 36 | ...... | 914.4 | $38\frac{1}{2}$ | 38.500 | 977.9 |
| $33\frac{9}{16}$ | 33.563 | 852.5 | $36\frac{1}{16}$ | 36.063 | 916.0 | $38\frac{9}{16}$ | 38.563 | 979.5 |
| $33\frac{5}{8}$ | 33.625 | 854.1 | $36\frac{1}{8}$ | 36.125 | 917.6 | $38\frac{5}{8}$ | 38.625 | 981.1 |
| $33\frac{11}{16}$ | 33.688 | 855.7 | $36\frac{3}{16}$ | 36.188 | 919.2 | $38\frac{11}{16}$ | 38.688 | 982.7 |
| $33\frac{3}{4}$ | 33.750 | 857.3 | $36\frac{1}{4}$ | 36.250 | 920.8 | $38\frac{3}{4}$ | 38.750 | 984.3 |
| $33\frac{13}{16}$ | 33.813 | 858.8 | $36\frac{5}{16}$ | 36.313 | 922.3 | $38\frac{13}{16}$ | 38.813 | 985.8 |
| $33\frac{7}{8}$ | 33.875 | 860.4 | $36\frac{3}{8}$ | 36.375 | 923.9 | $38\frac{7}{8}$ | 38.875 | 987.4 |
| $33\frac{15}{16}$ | 33.938 | 862.0 | $36\frac{7}{16}$ | 36.438 | 925.5 | $38\frac{15}{16}$ | 38.938 | 989.0 |
| 34 | ...... | 863.6 | $36\frac{1}{2}$ | 36.500 | 927.1 | 39 | ...... | 990.6 |
| $34\frac{1}{16}$ | 34.063 | 865.2 | $36\frac{9}{16}$ | 36.563 | 928.7 | $39\frac{1}{16}$ | 39.063 | 992.2 |
| $34\frac{1}{8}$ | 34.125 | 866.8 | $36\frac{5}{8}$ | 36.625 | 930.3 | $39\frac{1}{8}$ | 39.125 | 993.8 |
| $34\frac{3}{16}$ | 34.188 | 868.4 | $36\frac{11}{16}$ | 36.688 | 931.9 | $39\frac{3}{16}$ | 39.188 | 995.4 |
| $34\frac{1}{4}$ | 34.250 | 870.0 | $36\frac{3}{4}$ | 36.750 | 933.5 | $39\frac{1}{4}$ | 39.250 | 997.0 |
| $34\frac{5}{16}$ | 34.313 | 871.5 | $36\frac{13}{16}$ | 36.813 | 935.0 | $39\frac{5}{16}$ | 39.313 | 998.5 |
| $34\frac{3}{8}$ | 34.375 | 873.1 | $36\frac{7}{8}$ | 36.875 | 936.6 | $39\frac{3}{8}$ | 39.375 | 1000.1 |
| $34\frac{7}{16}$ | 34.438 | 874.7 | $36\frac{15}{16}$ | 36.938 | 938.2 | $39\frac{7}{16}$ | 39.438 | 1001.7 |
| $34\frac{1}{2}$ | 34.500 | 876.3 | 37 | ...... | 939.8 | $39\frac{1}{2}$ | 39.500 | 1003.3 |
| $34\frac{9}{16}$ | 34.563 | 877.9 | $37\frac{1}{16}$ | 37.063 | 941.4 | $39\frac{9}{16}$ | 39.563 | 1004.9 |
| $34\frac{5}{8}$ | 34.625 | 879.5 | $37\frac{1}{8}$ | 37.125 | 943.0 | $39\frac{5}{8}$ | 39.625 | 1006.5 |
| $34\frac{11}{16}$ | 34.688 | 881.1 | $37\frac{3}{16}$ | 37.188 | 944.6 | $39\frac{11}{16}$ | 39.688 | 1008.1 |
| $34\frac{3}{4}$ | 34.750 | 882.7 | $37\frac{1}{4}$ | 37.250 | 946.2 | $39\frac{3}{4}$ | 39.750 | 1009.7 |
| $34\frac{13}{16}$ | 34.813 | 884.2 | $37\frac{5}{16}$ | 37.313 | 947.7 | $39\frac{13}{16}$ | 39.813 | 1011.2 |
| $34\frac{7}{8}$ | 34.875 | 885.8 | $37\frac{3}{8}$ | 37.375 | 949.3 | $39\frac{7}{8}$ | 39.875 | 1012.8 |
| $34\frac{15}{16}$ | 34.938 | 887.4 | $37\frac{7}{16}$ | 37.438 | 950.9 | $39\frac{15}{16}$ | 39.938 | 1014.4 |
| 35 | ...... | 889.0 | $37\frac{1}{2}$ | 37.500 | 952.5 | 40 | ...... | 1016.0 |
| $35\frac{1}{16}$ | 35:063 | 890.6 | $37\frac{9}{16}$ | 37.563 | 954.1 | | | |
| $35\frac{1}{8}$ | 35.125 | 892.2 | $37\frac{5}{8}$ | 37.625 | 955.7 | | | |

## Lengths. Millimeters to Inches. From 1 to 1,000 Units

Reduction factor: 1 millimeter = 0.03937 inch

| Millimeters | Ins. | Millimeters | Ins. | Millimeters | Ins. | Millimeters | Ins. | Millimeters | Ins. | Millimeters | Ins. | Millimeters | Ins. | Millimeters | Ins. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | 5 | 1.77 | 90 | = 3.54 | 5 | 5.32 | 180 | = 7.09 | 5 | 8.86 | 270 | =10.63 | 5 | 12.40 |
| 1 | = .039 | 6 | 1.81 | 1 | 3.58 | 6 | 5.35 | 1 | 7.13 | 6 | 8.90 | 1 | 10.67 | 6 | 12.44 |
| 2 | .079 | 7 | 1.85 | 2 | 3.62 | 7 | 5.39 | 2 | 7.17 | 7 | 8.94 | 2 | 10.71 | 7 | 12.48 |
| 3 | .118 | 8 | 1.89 | 3 | 3.66 | 8 | 5.43 | 3 | 7.20 | 8 | 8.98 | 3 | 10.75 | 8 | 12.52 |
| 4 | .157 | 9 | 1.93 | 4 | 3.70 | 9 | 5.47 | 4 | 7.24 | 9 | 9.02 | 4 | 10.79 | 9 | 12.56 |
| 5 | .197 | 50 | = 1.97 | 5 | 3.74 | 140 | = 5.51 | 5 | 7.28 | 230 | = 9.06 | 5 | 10.83 | 320 | =12.60 |
| 6 | .236 | 1 | 2.01 | 6 | 3.78 | 1 | 5.55 | 6 | 7.32 | 1 | 9.09 | 6 | 10.87 | 1 | 12.64 |
| 7 | .276 | 2 | 2.05 | 7 | 3.82 | 2 | 5.59 | 7 | 7.36 | 2 | 9.13 | 7 | 10.91 | 2 | 12.68 |
| 8 | .315 | 3 | 2.09 | 8 | 3.86 | 3 | 5.63 | 8 | 7.40 | 3 | 9.17 | 8 | 10.94 | 3 | 12.72 |
| 9 | .354 | 4 | 2.13 | 9 | 3.90 | 4 | 5.67 | 9 | 7.44 | 4 | 9.21 | 9 | 10.98 | 4 | 12.76 |
| 10 | = .394 | 5 | 2.17 | 100 | = 3.94 | 5 | 5.71 | 190 | = 7.48 | 5 | 9.25 | 280 | =11.02 | 5 | 12.80 |
| 1 | .433 | 6 | 2.20 | 1 | 3.98 | 6 | 5.75 | 1 | 7.52 | 6 | 9.29 | 1 | 11.06 | 6 | 12.83 |
| 2 | .472 | 7 | 2.24 | 2 | 4.02 | 7 | 5.79 | 2 | 7.56 | 7 | 9.33 | 2 | 11.10 | 7 | 12.87 |
| 3 | .512 | 8 | 2.28 | 3 | 4.06 | 8 | 5.83 | 3 | 7.60 | 8 | 9.37 | 3 | 11.14 | 8 | 12.91 |
| 4 | .551 | 9 | 2.32 | 4 | 4.09 | 9 | 5.87 | 4 | 7.64 | 9 | 9.41 | 4 | 11.18 | 9 | 12.95 |
| 5 | .591 | 60 | = 2.36 | 5 | 4.13 | 150 | = 5.91 | 5 | 7.68 | 240 | = 9.45 | 5 | 11.22 | 330 | =12.99 |
| 6 | .630 | 1 | 2.40 | 6 | 4.17 | 1 | 5.95 | 6 | 7.72 | 1 | 9.49 | 6 | 11.26 | 1 | 13.03 |
| 7 | .669 | 2 | 2.44 | 7 | 4.21 | 2 | 5.98 | 7 | 7.76 | 2 | 9.53 | 7 | 11.30 | 2 | 13.07 |
| 8 | .709 | 3 | 2.48 | 8 | 4.25 | 3 | 6.02 | 8 | 7.80 | 3 | 9.57 | 8 | 11.34 | 3 | 13.11 |
| 9 | .748 | 4 | 2.52 | 9 | 4.29 | 4 | 6.06 | 9 | 7.83 | 4 | 9.61 | 9 | 11.38 | 4 | 13.15 |
| 20 | = .79 | 5 | 2.56 | 110 | = 4.33 | 5 | 6.10 | 200 | = 7.87 | 5 | 9.65 | 290 | =11.42 | 5 | 13.19 |
| 1 | .83 | 6 | 2.60 | 1 | 4.37 | 6 | 6.14 | 1 | 7.91 | 6 | 9.69 | 1 | 11.46 | 6 | 13.23 |
| 2 | .87 | 7 | 2.64 | 2 | 4.41 | 7 | 6.18 | 2 | 7.95 | 7 | 9.72 | 2 | 11.50 | 7 | 13.27 |
| 3 | .91 | 8 | 2.68 | 3 | 4.45 | 8 | 6.22 | 3 | 7.99 | 8 | 9.76 | 3 | 11.54 | 8 | 13.31 |
| 4 | .94 | 9 | 2.72 | 4 | 4.49 | 9 | 6.26 | 4 | 8.03 | 9 | 9.80 | 4 | 11.57 | 9 | 13.35 |
| 5 | .98 | 70 | = 2.76 | 5 | 4.53 | 160 | = 6.30 | 5 | 8.07 | 250 | = 9.84 | 5 | 11.61 | 340 | =13.39 |
| 6 | 1.02 | 1 | 2.80 | 6 | 4.57 | 1 | 6.34 | 6 | 8.11 | 1 | 9.88 | 6 | 11.65 | 1 | 13.43 |
| 7 | 1.06 | 2 | 2.83 | 7 | 4.61 | 2 | 6.38 | 7 | 8.15 | 2 | 9.92 | 7 | 11.69 | 2 | 13.46 |
| 8 | 1.10 | 3 | 2.87 | 8 | 4.65 | 3 | 6.42 | 8 | 8.19 | 3 | 9.96 | 8 | 11.73 | 3 | 13.50 |
| 9 | 1.14 | 4 | 2.91 | 9 | 4.69 | 4 | 6.46 | 9 | 8.23 | 4 | 10.00 | 9 | 11.77 | 4 | 13.54 |
| 30 | = 1.18 | 5 | 2.95 | 120 | = 4.72 | 5 | 6.50 | 210 | = 8.27 | 5 | 10.04 | 300 | =11.81 | 5 | 13.58 |
| 1 | 1.22 | 6 | 2.99 | 1 | 4.76 | 6 | 6.54 | 1 | 8.31 | 6 | 10.08 | 1 | 11.85 | 6 | 13.62 |
| 2 | 1.26 | 7 | 3.03 | 2 | 4.80 | 7 | 6.57 | 2 | 8.35 | 7 | 10.12 | 2 | 11.89 | 7 | 13.66 |
| 3 | 1.30 | 8 | 3.07 | 3 | 4.84 | 8 | 6.61 | 3 | 8.39 | 8 | 10.16 | 3 | 11.93 | 8 | 13.70 |
| 4 | 1.34 | 9 | 3.11 | 4 | 4.88 | 9 | 6.65 | 4 | 8.43 | 9 | 10.20 | 4 | 11.97 | 9 | 13.74 |
| 5 | 1.38 | 80 | = 3.15 | 5 | 4.92 | 170 | = 6.69 | 5 | 8.46 | 260 | =10.24 | 5 | 12.01 | 350 | =13.78 |
| 6 | 1.42 | 1 | 3.19 | 6 | 4.96 | 1 | 6.73 | 6 | 8.50 | 1 | 10.28 | 6 | 12.05 | 1 | 13.82 |
| 7 | 1.46 | 2 | 3.23 | 7 | 5.00 | 2 | 6.77 | 7 | 8.54 | 2 | 10.31 | 7 | 12.09 | 2 | 13.86 |
| 8 | 1.50 | 3 | 3.27 | 8 | 5.04 | 3 | 6.81 | 8 | 8.58 | 3 | 10.35 | 8 | 12.13 | 3 | 13.90 |
| 9 | 1.54 | 4 | 3.31 | 9 | 5.08 | 4 | 6.85 | 9 | 8.62 | 4 | 10.39 | 9 | 12.17 | 4 | 13.94 |
| 40 | = 1.57 | 5 | 3.35 | 130 | = 5.12 | 5 | 6.89 | 220 | = 8.66 | 5 | 10.43 | 310 | =12.20 | 5 | 13.98 |
| 1 | 1.61 | 6 | 3.39 | 1 | 5.16 | 6 | 6.93 | 1 | 8.70 | 6 | 10.47 | 1 | 12.24 | 6 | 14.02 |
| 2 | 1.65 | 7 | 3.43 | 2 | 5.20 | 7 | 6.97 | 2 | 8.74 | 7 | 10.51 | 2 | 12.28 | 7 | 14.06 |
| 3 | 1.69 | 8 | 3.46 | 3 | 5.24 | 8 | 7.01 | 3 | 8.78 | 8 | 10.55 | 3 | 12.32 | 8 | 14.09 |
| 4 | 1.73 | 9 | 3.50 | 4 | 5.28 | 9 | 7.05 | 4 | 8.82 | 9 | 10.59 | 4 | 12.36 | 9 | 14.13 |

## Lengths. Millimeters to Inches—(*Cont.*)

| Millimeters | Ins. | Millimeters | Ins. | Millimeters | Ins. | Millimeters | Ins. | Millimeters | Ins. | Millimeters | Ins. | Millimeters | Ins. | Millimeters | Ins. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 360 | =14.17 | 5 | 15.94 | 450 | =17.72 | 5 | 19.49 | 540 | =21.26 | 5 | 23.03 | 630 | =24.80 | 5 | 26.57 |
| 1 | 14.21 | 6 | 15.98 | 1 | 17.76 | 6 | 19.53 | 1 | 21.30 | 6 | 23.07 | 1 | 24.84 | 6 | 26.61 |
| 2 | 14.25 | 7 | 16.02 | 2 | 17.80 | 7 | 19.57 | 2 | 21.34 | 7 | 23.11 | 2 | 24.88 | 7 | 26.65 |
| 3 | 14.29 | 8 | 16.06 | 3 | 17.83 | 8 | 19.61 | 3 | 21.38 | 8 | 23.15 | 3 | 24.92 | 8 | 26.69 |
| 4 | 14.33 | 9 | 16.10 | 4 | 17.87 | 9 | 19.65 | 4 | 21.42 | 9 | 23.19 | 4 | 24.96 | 9 | 26.73 |
| 5 | 14.37 | 410 | =16.14 | 5 | 17.91 | 500 | =19.69 | 5 | 21.46 | 590 | =23.23 | 5 | 25.00 | 680 | =26.77 |
| 6 | 14.41 | 1 | 16.18 | 6 | 17.95 | 1 | 19.72 | 6 | 21.50 | 1 | 23.27 | 6 | 25.04 | 1 | 26.81 |
| 7 | 14.45 | 2 | 16.22 | 7 | 17.99 | 2 | 19.76 | 7 | 21.54 | 2 | 23.31 | 7 | 25.08 | 2 | 26.85 |
| 8 | 14.49 | 3 | 16.26 | 8 | 18.03 | 3 | 19.80 | 8 | 21.57 | 3 | 23.35 | 8 | 25.12 | 3 | 26.89 |
| 9 | 14.53 | 4 | 16.30 | 9 | 18.07 | 4 | 19.84 | 9 | 21.61 | 4 | 23.39 | 9 | 25.16 | 4 | 26.93 |
| 370 | =14.57 | 5 | 16.34 | 460 | =18.11 | 5 | 19.88 | 550 | =21.65 | 5 | 23.43 | 640 | =25.20 | 5 | 26.97 |
| 1 | 14.61 | 6 | 16.38 | 1 | 18.15 | 6 | 19.92 | 1 | 21.69 | 6 | 23.46 | 1 | 25.24 | 6 | 27.01 |
| 2 | 14.65 | 7 | 16.42 | 2 | 18.19 | 7 | 19.96 | 2 | 21.73 | 7 | 23.50 | 2 | 25.28 | 7 | 27.05 |
| 3 | 14.69 | 8 | 16.46 | 3 | 18.23 | 8 | 20.00 | 3 | 21.77 | 8 | 23.54 | 3 | 25.31 | 8 | 27.09 |
| 4 | 14.72 | 9 | 16.50 | 4 | 18.27 | 9 | 20.04 | 4 | 21.81 | 9 | 23.58 | 4 | 25.35 | 9 | 27.13 |
| 5 | 14.76 | 420 | =16.54 | 5 | 18.31 | 510 | =20.08 | 5 | 21.85 | 600 | =23.62 | 5 | 25.39 | 690 | =27.17 |
| 6 | 14.80 | 1 | 16.57 | 6 | 18.35 | 1 | 20.12 | 6 | 21.89 | 1 | 23.66 | 6 | 25.43 | 1 | 27.20 |
| 7 | 14.84 | 2 | 16.61 | 7 | 18.39 | 2 | 20.16 | 7 | 21.93 | 2 | 23.70 | 7 | 25.47 | 2 | 27.24 |
| 8 | 14.88 | 3 | 16.65 | 8 | 18.43 | 3 | 20.20 | 8 | 21.97 | 3 | 23.74 | 8 | 25.51 | 3 | 27.28 |
| 9 | 14.92 | 4 | 16.69 | 9 | 18.46 | 4 | 20.24 | 9 | 22.01 | 4 | 23.78 | 9 | 25.55 | 4 | 27.32 |
| 380 | =14.96 | 5 | 16.73 | 470 | =18.50 | 5 | 20.28 | 560 | =22.05 | 5 | 23.82 | 650 | =25.59 | 5 | 27.36 |
| 1 | 15.00 | 6 | 16.77 | 1 | 18.54 | 6 | 20.31 | 1 | 22.09 | 6 | 23.86 | 1 | 25.63 | 6 | 27.40 |
| 2 | 15.04 | 7 | 16.81 | 2 | 18.58 | 7 | 20.35 | 2 | 22.13 | 7 | 23.90 | 2 | 25.67 | 7 | 27.44 |
| 3 | 15.08 | 8 | 16.85 | 3 | 18.62 | 8 | 20.39 | 3 | 22.17 | 8 | 23.94 | 3 | 25.71 | 8 | 27.48 |
| 4 | 15.12 | 9 | 16.89 | 4 | 18.66 | 9 | 20.43 | 4 | 22.20 | 9 | 23.98 | 4 | 25.75 | 9 | 27.52 |
| 5 | 15.16 | 430 | =16.93 | 5 | 18.70 | 520 | =20.47 | 5 | 22.24 | 610 | =24.02 | 5 | 25.79 | 700 | =27.56 |
| 6 | 15.20 | 1 | 16.97 | 6 | 18.74 | 1 | 20.51 | 6 | 22.28 | 1 | 24.06 | 6 | 25.83 | 1 | 27.60 |
| 7 | 15.24 | 2 | 17.01 | 7 | 18.78 | 2 | 20.55 | 7 | 22.32 | 2 | 24.09 | 7 | 25.87 | 2 | 27.64 |
| 8 | 15.28 | 3 | 17.05 | 8 | 18.82 | 3 | 20.59 | 8 | 22.36 | 3 | 24.13 | 8 | 25.91 | 3 | 27.68 |
| 9 | 15.31 | 4 | 17.09 | 9 | 18.86 | 4 | 20.63 | 9 | 22.40 | 4 | 24.17 | 9 | 25.94 | 4 | 27.72 |
| 390 | =15.35 | 5 | 17.13 | 480 | =18.90 | 5 | 20.67 | 570 | =22.44 | 5 | 24.21 | 660 | =25.98 | 5 | 27.76 |
| 1 | 15.39 | 6 | 17.17 | 1 | 18.94 | 6 | 20.71 | 1 | 22.48 | 6 | 24.25 | 1 | 26.02 | 6 | 27.80 |
| 2 | 15.43 | 7 | 17.20 | 2 | 18.98 | 7 | 20.75 | 2 | 22.52 | 7 | 24.29 | 2 | 26.06 | 7 | 27.83 |
| 3 | 15.47 | 8 | 17.24 | 3 | 19.02 | 8 | 20.79 | 3 | 22.56 | 8 | 24.33 | 3 | 26.10 | 8 | 27.87 |
| 4 | 15.51 | 9 | 17.28 | 4 | 19.06 | 9 | 20.83 | 4 | 22.60 | 9 | 24.37 | 4 | 26.14 | 9 | 27.91 |
| 5 | 15.55 | 440 | =17.32 | 5 | 19.09 | 530 | =20.87 | 5 | 22.64 | 620 | =24.41 | 5 | 26.18 | 710 | =27.95 |
| 6 | 15.59 | 1 | 17.36 | 6 | 19.13 | 1 | 20.91 | 6 | 22.68 | 1 | 24.45 | 6 | 26.22 | 1 | 27.99 |
| 7 | 15.63 | 2 | 17.40 | 7 | 19.17 | 2 | 20.94 | 7 | 22.72 | 2 | 24.49 | 7 | 26.26 | 2 | 28.03 |
| 8 | 15.67 | 3 | 17.44 | 8 | 19.21 | 3 | 20.98 | 8 | 22.76 | 3 | 24.53 | 8 | 26.30 | 3 | 28.07 |
| 9 | 15.71 | 4 | 17.48 | 9 | 19.25 | 4 | 21.02 | 9 | 22.80 | 4 | 24.57 | 9 | 26.34 | 4 | 28.11 |
| 400 | =15.75 | 5 | 17.52 | 490 | =19.29 | 5 | 21.06 | 580 | =22.83 | 5 | 24.61 | 670 | =26.38 | 5 | 28.15 |
| 1 | 15.79 | 6 | 17.56 | 1 | 19.33 | 6 | 21.10 | 1 | 22.87 | 6 | 24.65 | 1 | 26.42 | 6 | 28.19 |
| 2 | 15.83 | 7 | 17.60 | 2 | 19.37 | 7 | 21.14 | 2 | 22.91 | 7 | 24.68 | 2 | 26.46 | 7 | 28.23 |
| 3 | 15.87 | 8 | 17.64 | 3 | 19.41 | 8 | 21.18 | 3 | 22.95 | 8 | 24.72 | 3 | 26.50 | 8 | 28.27 |
| 4 | 15.91 | 9 | 17.68 | 4 | 19.45 | 9 | 21.22 | 4 | 22.99 | 9 | 24.76 | 4 | 26.54 | 9 | 28.31 |

## Lengths. Millimeters to Inches—(*Cont.*)

| Milli-meters | Ins. | Milli-meters | Ins. | Milli-meters | Ins. | Milli-meters | Ins. | Milli-meters | Ins. | Milli-meters | Ins. | Milli-meters | Ins. | Milli-meters | Ins. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 720 | =28.35 | 5 | 29.72 | 790 | =31.10 | 5 | 32.48 | 860 | =33.86 | 5 | 35.24 | 930 | =36.61 | 5 | 37.99 |
| 1 | 28.39 | 6 | 29.76 | 1 | 31.14 | 6 | 32.52 | 1 | 33.90 | 6 | 35.28 | 1 | 36.65 | 6 | 38.03 |
| 2 | 28.43 | 7 | 29.80 | 2 | 31.18 | 7 | 32.56 | 2 | 33.94 | 7 | 35.31 | 2 | 36.69 | 7 | 38.07 |
| 3 | 28.46 | 8 | 29.84 | 3 | 31.22 | 8 | 32.60 | 3 | 33.98 | 8 | 35.35 | 3 | 36.73 | 8 | 38.11 |
| 4 | 28.50 | 9 | 29.88 | 4 | 31.26 | 9 | 32.64 | 4 | 34.02 | 9 | 35.39 | 4 | 36.77 | 9 | 38.15 |
| 5 | 28.54 | 760 | =29.92 | 5 | 31.30 | 830 | =32.68 | 5 | 34.06 | 900 | =35.43 | 5 | 36.81 | 970 | =38.19 |
| 6 | 28.58 | 1 | 29.96 | 6 | 31.34 | 1 | 32.72 | 6 | 34.09 | 1 | 35.47 | 6 | 36.85 | 1 | 38.23 |
| 7 | 28.62 | 2 | 30.00 | 7 | 31.38 | 2 | 32.76 | 7 | 34.13 | 2 | 35.51 | 7 | 36.89 | 2 | 38.27 |
| 8 | 28.66 | 3 | 30.04 | 8 | 31.42 | 3 | 32.80 | 8 | 34.17 | 3 | 35.55 | 8 | 36.93 | 3 | 38.31 |
| 9 | 28.70 | 4 | 30.08 | 9 | 31.46 | 4 | 32.83 | 9 | 34.21 | 4 | 35.59 | 9 | 36.97 | 4 | 38.35 |
| 730 | =28.74 | 5 | 30.12 | 800 | =31.50 | 5 | 32.87 | 870 | =34.25 | 5 | 35.63 | 940 | =37.01 | 5 | 38.39 |
| 1 | 28.78 | 6 | 30.16 | 1 | 31.54 | 6 | 32.91 | 1 | 34.29 | 6 | 35.67 | 1 | 37.05 | 6 | 38.43 |
| 2 | 28.82 | 7 | 30.20 | 2 | 31.57 | 7 | 32.95 | 2 | 34.33 | 7 | 35.71 | 2 | 37.09 | 7 | 38.46 |
| 3 | 28.86 | 8 | 30.24 | 3 | 31.61 | 8 | 32.99 | 3 | 34.37 | 8 | 35.75 | 3 | 37.13 | 8 | 38.50 |
| 4 | 28.90 | 9 | 30.28 | 4 | 31.65 | 9 | 33.03 | 4 | 34.41 | 9 | 35.79 | 4 | 37.17 | 9 | 38.54 |
| 5 | 28.94 | 770 | =30.31 | 5 | 31.69 | 840 | =33.07 | 5 | 34.45 | 910 | =35.83 | 5 | 37.20 | 980 | =38.58 |
| 6 | 28.98 | 1 | 30.35 | 6 | 31.73 | 1 | 33.11 | 6 | 34.49 | 1 | 35.87 | 6 | 37.24 | 1 | 38.62 |
| 7 | 29.02 | 2 | 30.39 | 7 | 31.77 | 2 | 33.15 | 7 | 34.53 | 2 | 35.91 | 7 | 37.28 | 2 | 38.66 |
| 8 | 29.06 | 3 | 30.43 | 8 | 31.81 | 3 | 33.19 | 8 | 34.57 | 3 | 35.94 | 8 | 37.32 | 3 | 38.70 |
| 9 | 29.09 | 4 | 30.47 | 9 | 31.85 | 4 | 33.23 | 9 | 34.61 | 4 | 35.98 | 9 | 37.36 | 4 | 38.74 |
| 740 | =29.13 | 5 | 30.51 | 810 | =31.89 | 5 | 33.27 | 880 | =34.65 | 5 | 36.02 | 950 | =37.40 | 5 | 38.78 |
| 1 | 29.17 | 6 | 30.55 | 1 | 31.93 | 6 | 33.31 | 1 | 34.68 | 6 | 36.06 | 1 | 37.44 | 6 | 38.82 |
| 2 | 29.21 | 7 | 30.59 | 2 | 31.97 | 7 | 33.25 | 2 | 34.72 | 7 | 36.10 | 2 | 37.48 | 7 | 38.86 |
| 3 | 29.25 | 8 | 30.63 | 3 | 32.01 | 8 | 33.39 | 3 | 34.76 | 8 | 36.14 | 3 | 37.52 | 8 | 38.90 |
| 4 | 29.29 | 9 | 30.67 | 4 | 32.05 | 9 | 33.43 | 4 | 34.80 | 9 | 36.18 | 4 | 37.56 | 9 | 38.94 |
| 5 | 29.33 | 780 | =30.71 | 5 | 32.09 | 850 | =33.46 | 5 | 34.84 | 920 | =36.22 | 5 | 37.60 | 990 | =38.98 |
| 6 | 29.37 | 1 | 39.75 | 6 | 32.13 | 1 | 33.50 | 6 | 34.88 | 1 | 36.26 | 6 | 37.64 | 1 | 39.02 |
| 7 | 29.41 | 2 | 30.79 | 7 | 32.17 | 2 | 33.54 | 7 | 34.92 | 2 | 36.30 | 7 | 37.68 | 2 | 39.06 |
| 8 | 29.45 | 3 | 30.83 | 8 | 32.20 | 3 | 33.58 | 8 | 34.96 | 3 | 36.34 | 8 | 37.72 | 3 | 39.09 |
| 9 | 29.49 | 4 | 30.87 | 9 | 32.24 | 4 | 33.62 | 9 | 35.00 | 4 | 36.38 | 9 | 37.76 | 4 | 39.13 |
| 750 | =29.53 | 5 | 30.91 | 820 | =32.28 | 5 | 33.66 | 890 | =35.04 | 5 | 36.42 | 960 | =37.80 | 5 | 39.17 |
| 1 | 29.57 | 6 | 30.94 | 1 | 32.32 | 6 | 33.70 | 1 | 35.08 | 6 | 36.46 | 1 | 37.83 | 6 | 39.21 |
| 2 | 29.61 | 7 | 30.98 | 2 | 32.36 | 7 | 33.74 | 2 | 35.12 | 7 | 36.50 | 2 | 37.87 | 7 | 39.25 |
| 3 | 29.65 | 8 | 31.02 | 3 | 32.40 | 8 | 33.78 | 3 | 35.16 | 8 | 36.54 | 3 | 37.91 | 8 | 39.29 |
| 4 | 29.68 | 9 | 31.06 | 4 | 32.44 | 9 | 33.82 | 4 | 35.20 | 9 | 36.57 | | [illegible]7.95 | 9 | 39.33 |
| | | | | | | | | | | | | | | 1000 | 39.37 |

1000 millimeters = 1 meter = 39.37 inches = 3.28 feet = 1.09 yards.

## Comparison of Customary and Metric Units from 1 to 10

Reduction factors: 1 meter = 39.37 inches
1 inch = 25.4001 millimeters

### Lengths

| Inches | Millimeters | Ins. | Centimeters | Feet | Meters | U.S.Yds. | Meters | U.S.Miles. | Kilom. |
|---|---|---|---|---|---|---|---|---|---|
| 0.039 | 1 | 0.394 | 1 | 1 | 0.305 | 1 | 0.914 | 0.621 | 1 |
| .079 | 2 | .787 | 2 | 2 | .610 | 1.094 | 1 | 1 | 1.609 |
| .118 | 3 | 1 | 2.540 | 3 | .914 | 2 | 1.829 | 1.243 | 2 |
| .157 | 4 | 1.181 | 3 | 3.281 | 1 | 2.187 | 2 | 1.864 | 3 |
| .197 | 5 | 1.575 | 4 | 4 | 1.219 | 3 | 2.743 | 2 | 3.219 |
| .236 | 6 | 1.969 | 5 | 5 | 1.524 | 3.281 | 3 | 2.485 | 4 |
| .276 | 7 | 2 | 5.080 | 6 | 1.829 | 4 | 3.658 | 3 | 4.828 |
| .315 | 8 | 2.362 | 6 | 6.562 | 2 | 4.374 | 4 | 3.107 | 5 |
| .354 | 9 | 2.756 | 7 | 7 | 2.134 | 5 | 4.572 | 3.728 | 6 |
| 1 | 25.400 | 3 | 7.620 | 8 | 2.438 | 5.468 | 5 | 4 | 6.437 |
| 2 | 50.800 | 3.150 | 8 | 9 | 2.743 | 6 | 5.486 | 4.350 | 7 |
| 3 | 76.200 | 3.543 | 9 | 9.843 | 3 | 6.562 | 6 | 4.971 | 8 |
| 4 | 101.600 | 4 | 10.160 | 13.123 | 4 | 7 | 6.401 | 5 | 8.047 |
| 5 | 127.000 | 5 | 12.700 | 16.404 | 5 | 7.655 | 7 | 5.592 | 9 |
| 6 | 152.400 | 6 | 15.240 | 19.685 | 6 | 8 | 7.315 | 6 | 9.656 |
| 7 | 177.800 | 7 | 17.780 | 22.966 | 7 | 8.749 | 8 | 7 | 11.265 |
| 8 | 203.200 | 8 | 20.320 | 26.247 | 8 | 9 | 8.230 | 8 | 12.875 |
| 9 | 228.600 | 9 | 22.860 | 29.528 | 9 | 9.843 | 9 | 9 | 14.484 |

## Comparison of Customary and Metric Units from 1 to 10

Reduction factors:

| | | | |
|---|---|---|---|
| 1 sq. meter = 1.196 sq. yard | | 1 sq. yard = 0.836 sq. meter | |
| 1 sq. meter = 10.764 sq. foot | | 1 sq. foot = 0.0929 sq. meter | |
| 1 sq. centimeter = 0.155 sq. inch | | 1 sq. inch = 6.452 sq. centimeter | |
| 1 sq. millimeter = 0.00155 sq. inch | | 1 sq. inch = 645.16 sq. millimeter | |

### Areas

| Square Inches | Square Millimeters | Square Inches | Square Centimeters | Square Feet | Square Meters | Square Yards | Square Meters | Square Miles | Square Kilometers |
|---|---|---|---|---|---|---|---|---|---|
| 0.002 | 1 | 0.155 | 1 | 1 | 0.093 | 1 | 0.836 | 0.386 | 1 |
| .003 | 2 | .310 | 2 | 2 | .186 | 1.196 | 1 | .772 | 2 |
| .005 | 3 | .465 | 3 | 3 | .279 | 2 | 1.672 | 1 | 2.59 |
| .006 | 4 | .620 | 4 | 4 | .372 | 2.392 | 2 | 1.158 | 3 |
| .008 | 5 | .775 | 5 | 5 | .465 | 3 | 2.508 | 1.544 | 4 |
| .009 | 6 | .930 | 6 | 6 | .557 | 3.588 | 3 | 1.931 | 5 |
| .011 | 7 | 1 | 6.452 | 7 | .650 | 4 | 3.345 | 2 | 5.18 |
| .012 | 8 | 1.085 | 7 | 8 | .743 | 4.784 | 4 | 2.317 | 6 |
| .014 | 9 | 1.240 | 8 | 9 | .836 | 5 | 4.181 | 2.703 | 7 |

## Comparison of Customary and Metric Units from 1 to 10—(*Cont.*)

### Areas—(*Cont.*)

| Square Inches | Square Millimeters | Square Inches | Square Centimeters | Square Feet | Square Meters | Square Yards | Square Meters | Square Miles | Square Kilometers |
|---|---|---|---|---|---|---|---|---|---|
| 1 = | 645.16 | 1.395 = | 9 | 10.764 = | 1 | 5.980 = | 5 | 3 = | 7.77 |
| 2 = | 1290.33 | 2 = | 12.903 | 21.528 = | 2 | 6 = | 5.017 | 3.089 = | 8 |
| 3 = | 1935.49 | 3 = | 19.355 | 32.292 = | 3 | 7 = | 5.853 | 3.475 = | 9 |
| 4 = | 2580.65 | 4 = | 25.807 | 43.055 = | 4 | 7.176 = | 6 | 4 = | 10.36 |
| 5 = | 3225.81 | 5 = | 32.258 | 53.819 = | 5 | 8 = | 6.689 | 5 = | 12.95 |
| 6 = | 3870.98 | 6 = | 38.710 | 64.583 = | 6 | 8.372 = | 7 | 6 = | 15.54 |
| 7 = | 4516.14 | 7 = | 45.161 | 75.347 = | 7 | 9 = | 7.525 | 7 = | 18.13 |
| 8 = | 5161.30 | 8 = | 51.613 | 86.111 = | 8 | 9.568 = | 8 | 8 = | 20.72 |
| 9 = | 5806.46 | 9 = | 58.065 | 96.875 = | 9 | 10.764 = | 9 | 9 = | 23.31 |

## Comparison of Customary and Metric Units from 1 to 10

Reduction factors:

| | | | |
|---|---|---|---|
| 1 cu. meter | = 1.308 cu. yd | 1 cu. yd. = | 0.765 cu. meter |
| 1 cu. meter | = 35.314 cu. ft. | 1 cu. ft. = | 0.028 cu. meter |
| 1 cu. centimeter | = 0.061 cu. in. | 1 cu. in. = | 16.387 cu. centimeters |
| 1 cu. millimeter | = 0.000061 cu. in. | 1 cu. in. = | 16.387 cu. millimeters |

| Volumes | | | | | | | | Areas—*Continued* | |
|---|---|---|---|---|---|---|---|---|---|
| Cubic Inches | Cubic Millimeters | Cubic Inches | Cubic Centimeters | Cubic Feet | Cubic Meters | Cubic Yards | Cubic Meters | Acres | Hectares |
| .000061 = | 1 | 0.061 = | 1 | 1 = | 0.028 | 1 = | 0.765 | 1 = | 0.405 |
| .000122 = | 2 | .122 = | 2 | 2 = | .057 | 1.308 = | 1 | 2 = | .809 |
| .000183 = | 3 | .183 = | 3 | 3 = | .085 | 2 = | 1.529 | 2.471 = | 1 |
| .000244 = | 4 | .244 = | 4 | 4 = | .113 | 2.616 = | 2 | 3 = | 1.214 |
| .000305 = | 5 | .305 = | 5 | 5 = | .142 | 3 = | 2.294 | 4 = | 1.619 |
| .000366 = | 6 | .366 = | 6 | 6 = | .170 | 3.924 = | 3 | 4.942 = | 2 |
| .000427 = | 7 | .427 = | 7 | 7 = | .198 | 4 = | 3.058 | 5 = | 2.023 |
| .000488 = | 8 | .488 = | 8 | 8 = | .227 | 5 = | 3.823 | 6 = | 2.428 |
| .000549 = | 9 | .549 = | 9 | 9 = | .255 | 5.232 = | 4 | 7 = | 2.833 |
| 1 = | 16387 | 1 = | 16.387 | 35.314 = | 1 | 6 = | 4.587 | 7.413 = | 3 |
| 2 = | 32774 | 2 = | 32.774 | 70.629 = | 2 | 6.540 = | 5 | 8 = | 3.238 |
| 3 = | 49162 | 3 = | 49.162 | 105.943 = | 3 | 7 = | 5.352 | 9 = | 3.642 |
| 4 = | 65549 | 4 = | 65.549 | 141.258 = | 4 | 7.848 = | 6 | 9.884 = | 4 |
| 5 = | 81936 | 5 = | 81.936 | 176.572 = | 5 | 8 = | 6.117 | 12.355 = | 5 |
| 6 = | 98323 | 6 = | 98.323 | 211.887 = | 6 | 9 = | 6.881 | 14.826 = | 6 |
| 7 = | 114710 | 7 = | 114.710 | 247.201 = | 7 | 9.156 = | 7 | 17.297 = | 7 |
| 8 = | 131097 | 8 = | 131.097 | 282.516 = | 8 | 10.464 = | 8 | 19.768 = | 8 |
| 9 = | 147485 | 9 = | 147.485 | 317.830 = | 9 | 11.772 = | 9 | 22.239 = | 9 |

# CUSTOMARY TO METRIC UNITS

### Comparison of Customary and Metric Units from 1 to 10

Reduction factors are as given in first line of each measure

#### Capacities

| U. S. Liquid Ounces | Milliliters (cc.) | U. S. Apoth Drams | Milliliters (cc.) | U. S. Apoth. Scruples | Milliliters (cc.) | U. S. Liquid Quarts | Liters | U. S. Liquid Gallons | Liters |
|---|---|---|---|---|---|---|---|---|---|
| 0.03381 | 1 | 0.2705 | 1 | 0.8115 | 1 | 1 | 0.94636 | 0.26417 | 1 |
| .068 | 2 | .541 | 2 | 1 | 1.2322 | 1.057 | 1 | .528 | 2 |
| .101 | 3 | .812 | 3 | 1.623 | 2 | 2 | 1.893 | .793 | 3 |
| .135 | 4 | 1 | 3.6967 | 2 | 2.465 | 2.113 | 2 | 1 | 3.78543 |
| .169 | 5 | 1.082 | 4 | 2.435 | 3 | 3 | 2.839 | 1.057 | 4 |
| .203 | 6 | 1.353 | 5 | 3 | 3.697 | 3.170 | 3 | 1.321 | 5 |
| .237 | 7 | 1.623 | 6 | 3.246 | 4 | 4 | 3.785 | 1.585 | 6 |
| .271 | 8 | 1.894 | 7 | 4 | 4.929 | 4.227 | 4 | 1.849 | 7 |
| .304 | 9 | 2 | 7.393 | 4.058 | 5 | 5 | 4.732 | 2 | 7.571 |
| 1 | 29.574 | 2.164 | 8 | 4.869 | 6 | 5.283 | 5 | 2.113 | 8 |
| 2 | 59.147 | 2.435 | 9 | 5 | 6.161 | 6 | 5.678 | 2.378 | 9 |
| 3 | 88.721 | 3 | 11.090 | 5.681 | 7 | 6.340 | 6 | 3 | 11.356 |
| 4 | 118.295 | 4 | 14.787 | 6 | 7.393 | 7 | 6.625 | 4 | 15.142 |
| 5 | 147.869 | 5 | 18.484 | 6.492 | 8 | 7.397 | 7 | 5 | 18.927 |
| 6 | 177.442 | 6 | 22.180 | 7 | 8.626 | 8 | 7.571 | 6 | 22.713 |
| 7 | 207.016 | 7 | 25.877 | 7.304 | 9 | 8.453 | 8 | 7 | 26.498 |
| 8 | 236.590 | 8 | 29.574 | 8 | 9.858 | 9 | 8.517 | 8 | 30.283 |
| 9 | 266.163 | 9 | 33.270 | 9 | 11.090 | 9.510 | 9 | 9 | 34.069 |

### Comparison of Customary and Metric Units from 1 to 10

#### Capacities—(*Cont.*)

| U. S. Dry Quarts | Liters | U. S. Pecks | Liters | U. S. Pecks | Dekaliters | U. S. Bushels | Hectoliters | U. S. Bushels per Acre | Hectoliters per Hectare |
|---|---|---|---|---|---|---|---|---|---|
| 0.9081 | 1 | 0.11351 | 1 | 1 | 0.8810 | 1 | 0.35239 | 1 | 0.87078 |
| 1 | 1.1012 | .227 | 2 | 1.1351 | 1 | 2 | .705 | 1.14840 | 1 |
| 1.816 | 2 | .341 | 3 | 2 | 1.762 | 2.838 | 1 | 2 | 1.742 |
| 2 | 2.203 | .454 | 4 | 2.270 | 2 | 3 | 1.057 | 2.967 | 2 |
| 2.724 | 3 | .568 | 5 | 3 | 2.643 | 4 | 1.410 | 3 | 2.612 |
| 3 | 3.304 | .681 | 6 | 3.405 | 3 | 5 | 1.762 | 3.445 | 3 |
| 3.632 | 4 | .795 | 7 | 4 | 3.524 | 5.675 | 2 | 4 | 3.483 |
| 4 | 4.405 | .908 | 8 | 4.540 | 4 | 6 | 2.114 | 4.594 | 4 |
| 4.540 | 5 | 1 | 8.810 | 5 | 4.405 | 7 | 2.467 | 5 | 4.354 |
| 5 | 5.506 | 1.022 | 9 | 5.676 | 5 | 8 | 2.819 | 5.742 | 5 |
| 5.449 | 6 | 2 | 17.620 | 6 | 5.286 | 8.513 | 3 | 6 | 5.225 |
| 6 | 6.607 | 3 | 26.429 | 6.811 | 6 | 9 | 3.172 | 6.890 | 6 |
| 6.357 | 7 | 4 | 35.239 | 7 | 6.167 | 11.351 | 4 | 7 | 6.095 |
| 7 | 7.709 | 5 | 44.049 | 7.946 | 7 | 14.189 | 5 | 8 | 6.966 |
| 7.265 | 8 | 6 | 52.859 | 8 | 7.048 | 17.026 | 6 | 8.039 | 7 |
| 8 | 8.810 | 7 | 61.669 | 9 | 7.929 | 19.864 | 7 | 9 | 7.837 |
| 8.173 | 9 | 8 | 70.479 | 9.081 | 8 | 22.702 | 8 | 9.187 | 8 |
| 9 | 9.911 | 9 | 79.288 | 10.216 | 9 | 25.540 | 9 | 10.336 | 9 |

## Comparison of Customary and Metric Units from 1 to 10

Reduction factors are as given in first line of each measure

### Masses

| Grains | Grams | Avoirdupois Ounces | Grams | Troy Ounces | Grams | Avoirdupois Pounds | Kilograms | Troy Pounds | Kilograms |
|---|---|---|---|---|---|---|---|---|---|
| 1 | =0.06480 | 0.03527 | =1 | 0.03215 | =1 | 1 | =0.45359 | 1 | =0.37324 |
| 2 | = .130 | .071 | =2 | .064 | =2 | 2 | = .907 | 2 | = .746 |
| 3 | = .194 | .106 | =3 | .096 | =3 | 2.20462 | =1 | 2.67923 | =1 |
| 4 | = .259 | .141 | =4 | .129 | =4 | 3 | =1.361 | 3 | =1.120 |
| 5 | = .324 | .176 | =5 | .161 | =5 | 4 | =1.814 | 4 | =1.493 |
| 6 | = .389 | .212 | =6 | .193 | =6 | 4.409 | =2 | 5 | =1.866 |
| 7 | = .454 | .247 | =7 | .225 | =7 | 5 | =2.268 | 5.358 | =2 |
| 8 | = .518 | .282 | =8 | .257 | =8 | 6 | =2.722 | 6 | =2.239 |
| 9 | = .583 | .317 | =9 | .289 | =9 | 6.614 | =3 | 7 | =2.613 |
| 15.4324 | =1 | 1 | = 28.3495 | 1 | = 31.10348 | 7 | =3.175 | 8 | =2.986 |
| 30.865 | =2 | 2 | = 56.699 | 2 | = 62.207 | 8 | =3.629 | 8.038 | =3 |
| 46.297 | =3 | 3 | = 85.049 | 3 | = 93.310 | 8.818 | =4 | 9 | =3.359 |
| 61.729 | =4 | 4 | =113.398 | 4 | =124.414 | 9 | =4.082 | 10.717 | =4 |
| 77.162 | =5 | 5 | =141.748 | 5 | =155.517 | 11.023 | =5 | 13.396 | =5 |
| 92.594 | =6 | 6 | =170.098 | 6 | =186.621 | 13.228 | =6 | 16.075 | =6 |
| 108.027 | =7 | 7 | =198.447 | 7 | =217.724 | 15.432 | =7 | 18.755 | =7 |
| 123.459 | =8 | 8 | =226.796 | 8 | =248.828 | 17.637 | =8 | 21.434 | =8 |
| 138.891 | =9 | 9 | =255.146 | 9 | =279.931 | 19.842 | =9 | 24.113 | =9 |

# COMPARISON OF THE VARIOUS TONS AND POUNDS IN USE IN THE UNITED STATES.

**FROM 1 TO 10 UNITS.**

| LONG TONS. | SHORT TONS. | METRIC TONS. | KILOGRAMS. | AVOIRDUPOIS POUNDS. | TROY POUNDS. |
|---|---|---|---|---|---|
| .00036735 | .00041143 | .00037324 | .37324 | .822857 | 1 |
| .00044643 | .00050000 | .00045359 | .45359 | 1 | 1.21528 |
| .00073469 | .00082286 | .00074648 | .74648 | 1.64571 | 2 |
| .00089286 | .00100000 | .00090718 | .90718 | 2 | 2.43056 |
| .00098421 | .00110231 | .00100000 | 1 | 2.20462 | 2.67923 |
| .00110204 | .00123429 | .00111973 | 1.11973 | 2.46857 | 3 |
| .00133929 | .00150000 | .00136078 | 1.36078 | 3 | 3.64583 |
| .00146939 | .00164571 | .00149297 | 1.49297 | 3.29143 | 4 |
| .00178571 | .00200000 | .00181437 | 1.81437 | 4 | 4.86111 |
| .00183673 | .00205714 | .00186621 | 1.86621 | 4.11429 | 5 |
| .00196841 | .00220462 | .00200000 | 2 | 4.40924 | 5.35846 |
| .00220408 | .00246857 | .00223945 | 2.23945 | 4.93714 | 6 |
| .00223214 | .00250000 | .00226796 | 2.26796 | 5 | 6.07639 |
| .00257143 | .00288000 | .00261269 | 2.61269 | 5.76000 | 7 |
| .00267857 | .00300000 | .00272155 | 2.72155 | 6 | 7.29167 |
| .00293878 | .00329143 | .00298593 | 2.98593 | 6.58286 | 8 |
| .00295262 | .00330693 | .00300000 | 3 | 6.61387 | 8.03769 |
| .00312500 | .00350000 | .00317515 | 3.17515 | 7 | 8.50694 |
| .00330612 | .00370286 | .00335918 | 3.35918 | 7.40571 | 9 |
| .00357143 | .00400000 | .00362874 | 3.62874 | 8 | 9.72222 |
| .00393683 | .00440924 | .00400000 | 4 | 8.81849 | 10.71691 |
| .00401786 | .00450000 | .00408233 | 4.08233 | 9 | 10.93750 |
| .00492103 | .00551156 | .00500000 | 5 | 11.0231 | 13.39614 |
| .00590524 | .00661387 | .00600000 | 6 | 13.2277 | 16.07537 |
| .00688944 | .00771618 | .00780000 | 7 | 15.4324 | 18.75460 |
| .00787365 | .00881849 | .00800000 | 8 | 17.6370 | 21.43383 |
| .00885786 | .00992080 | .0090000 | 9 | 19.8416 | 24.11306 |
| .89287 | 1 | .90718 | 907.18 | 2,000.00 | 2,430.56 |
| .98421 | 1.10231 | 1 | 1,000.00 | 2,204.62 | 2,679.23 |
| 1 | 1.12000 | 1.01605 | 1,016.05 | 2,240.00 | 2,722.22 |
| 1.78571 | 2 | 1.81437 | 1,814.37 | 4,000.00 | 4,861.11 |
| 1.96841 | 2.20462 | 2 | 2,000.00 | 4,409.24 | 5,358.46 |
| 2 | 2.24000 | 2.03209 | 2,032.09 | 4,480.00 | 5,444.44 |
| 2.67857 | 3 | 2.72155 | 2,721.55 | 6,000.00 | 7,291.67 |
| 2.95262 | 3.30693 | 3 | 3,000.00 | 6,613.87 | 8,037.69 |
| 3 | 3.36000 | 3.04814 | 3,048.14 | 6,720.00 | 8,166.67 |
| 3.57143 | 4 | 3.62874 | 3,628.74 | 8,000.00 | 9,722.22 |
| 3.93683 | 4.40924 | 4 | 4,000.00 | 8,818.49 | 10,716.91 |
| 4 | 4.48000 | 4.06419 | 4,064.19 | 8,960.00 | 10,888.89 |
| 4.46429 | 5 | 4.53592 | 4,535.92 | 10,000.00 | 12,152.78 |
| 4.92103 | 5.51156 | 5 | 5,000.00 | 11,023.11 | 13,396.14 |
| 5 | 5.60000 | 5.08024 | 5,080.24 | 11,200.00 | 13,611.11 |
| 5.35714 | 6 | 5.44311 | 5,443.11 | 12,000.00 | 14,583.33 |
| 5.90524 | 6.61387 | 6 | 6,000.00 | 13,227.73 | 16,075.37 |
| 6 | 6.72000 | 6.09628 | 6,096.28 | 13,440.00 | 16,333.33 |
| 6.25000 | 7 | 6.35029 | 6,350.29 | 14,000.00 | 17,013.89 |
| 6.88944 | 7.71618 | 7 | 7,000.00 | 15,432.36 | 18,754.60 |
| 7 | 7.84000 | 7.11232 | 7,112.32 | 15,680.00 | 19,055.56 |
| 7.14286 | 8 | 7.25748 | 7,257.48 | 16,000.00 | 19,444.44 |
| 7.87365 | 8.81849 | 8 | 8,000.00 | 17,636.98 | 21,433.83 |
| 8 | 8.96000 | 8.12838 | 8,128.38 | 17,920.00 | 21,777.78 |
| 8.03571 | 9 | 8.16466 | 8,164.66 | 18,000.00 | 21,875.00 |
| 8.85786 | 9.92080 | 9 | 9,000.00 | 19,841.60 | 24,113.06 |
| 9 | 10.08000 | 9.14442 | 9,144.42 | 20,160.00 | 24,500.00 |

**ISSUED BY THE BUREAU OF STANDARDS**

## Lengths. Admiralty Knots to Statute Miles and Kilometers

Conversion factors: 1 Admiralty knot = 6080 feet
1 statute mile = 5280 feet
1 kilometer = 3280.833 feet
statute mile = Admiralty knot × 1.151515
kilometer = Admiralty knot × 1.8531877

| Knots per Hour | Miles | Kilometers | Speed | | Knots per Hour | Miles | Kilometers | Speed | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Feet per Minute | Feet per Second | | | | Feet per Minute | Feet per Second |
| 1 | 1.152 | 1.853 | 101.3 | 1.69 | 9¾ | 11.227 | 18.069 | 988. | 16.47 |
| 1¼ | 1.439 | 2.316 | 126.7 | 2.11 | 10 | 11.515 | 18.532 | 1013.3 | 16.89 |
| 1½ | 1.727 | 2.780 | 152.0 | 2.53 | 10¼ | 11.803 | 18.995 | 1038.7 | 17.31 |
| 1¾ | 2.015 | 3.243 | 177.3 | 2.96 | 10½ | 12.091 | 19.458 | 1064. | 17.73 |
| 2 | 2.303 | 3.706 | 202.7 | 3.38 | 10¾ | 12.379 | 19.922 | 1089.3 | 18.16 |
| 2¼ | 2.591 | 4.170 | 228. | 3.80 | 11 | 12.667 | 20.385 | 1114.7 | 18.58 |
| 2½ | 2.879 | 4.633 | 253.3 | 4.22 | 11¼ | 12.955 | 20.848 | 1140. | 19.00 |
| 2¾ | 3.167 | 5.096 | 278.7 | 4.64 | 11½ | 13.242 | 21.312 | 1165.3 | 19.42 |
| 3 | 3.455 | 5.560 | 304. | 5.07 | 11¾ | 13.530 | 21.775 | 1190.7 | 19.84 |
| 3¼ | 3.742 | 6.023 | 329.3 | 5.49 | 12 | 13.818 | 22.238 | 1216. | 20.27 |
| 3½ | 4.030 | 6.486 | 354.7 | 5.91 | 12¼ | 14.106 | 22.702 | 1241.3 | 20.69 |
| 3¾ | 4.318 | 6.949 | 380. | 6.33 | 12½ | 14.394 | 23.165 | 1266.7 | 21.11 |
| 4 | 4.606 | 7.413 | 405.3 | 6.76 | 12¾ | 14.682 | 23.628 | 1292. | 21.53 |
| 4¼ | 4.894 | 7.876 | 430.7 | 7.18 | 13 | 14.970 | 24.091 | 1317.3 | 21.96 |
| 4½ | 5.182 | 8.339 | 456. | 7.60 | 13¼ | 15.258 | 24.555 | 1342.7 | 22.38 |
| 4¾ | 5.470 | 8.803 | 481.3 | 8.02 | 13½ | 15.545 | 25.018 | 1368. | 22.80 |
| 5 | 5.758 | 9.266 | 506.7 | 8.44 | 13¾ | 15.833 | 25.481 | 1393.3 | 23.22 |
| 5¼ | 6.045 | 9.729 | 532. | 8.87 | 14 | 16.121 | 25.945 | 1418.7 | 23.64 |
| 5½ | 6.333 | 10.193 | 557.3 | 9.29 | 14¼ | 16.409 | 26.408 | 1444. | 24.07 |
| 5¾ | 6.621 | 10.656 | 582.7 | 9.71 | 14½ | 16 697 | 26.871 | 1469.3 | 24.49 |
| 6 | 6.909 | 11.119 | 608. | 10.13 | 14¾ | 16.985 | 27.335 | 1494.7 | 24.91 |
| 6¼ | 7.197 | 11.582 | 633.3 | 10.56 | 15 | 17.273 | 27.798 | 1520. | 25.33 |
| 6½ | 7.485 | 12.046 | 658.7 | 10.98 | 15¼ | 17.561 | 28.261 | 1545.3 | 25.76 |
| 6¾ | 7.773 | 12.509 | 684. | 11.40 | 15½ | 17.848 | 28.724 | 1570.7 | 26.18 |
| 7 | 8.061 | 12.972 | 709.3 | 11.82 | 15¾ | 18.136 | 29.188 | 1596. | 26.60 |
| 7¼ | 8.348 | 13.436 | 734.7 | 12.24 | 16 | 18.424 | 29.651 | 1621.3 | 27.02 |
| 7½ | 8.636 | 13.899 | 760. | 12.67 | 16¼ | 18.712 | 30.114 | 1646.7 | 27.44 |
| 7¾ | 8.924 | 14.362 | 785.3 | 13.09 | 16½ | 19.000 | 30.578 | 1672. | 27.87 |
| 8 | 9.212 | 14.826 | 810.7 | 13.51 | 16¾ | 19.288 | 31.041 | 1697.3 | 28.29 |
| 8¼ | 9.500 | 15.289 | 836. | 13.93 | 17 | 19.576 | 31.504 | 1722.7 | 28.71 |
| 8½ | 9.788 | 15.752 | 861.3 | 14.36 | 17¼ | 19.864 | 31.967 | 1748. | 29.13 |
| 8¾ | 10.076 | 16.215 | 886.7 | 14.78 | 17½ | 20.152 | 32.431 | 1773.3 | 29.56 |
| 9 | 10.364 | 16.679 | 912. | 15.20 | 17¾ | 20.439 | 32.894 | 1798.7 | 29.98 |
| 9¼ | 10.652 | 17.142 | 937.3 | 15.62 | 18 | 20.727 | 33.357 | 1824. | 30.40 |
| 9½ | 10.939 | 17.605 | 962.7 | 16.04 | 18¼ | 21.015 | 33.821 | 1849.3 | 30.82 |

LENGTHS. ADMIRALTY KNOTS TO STATUTE MILES AND KILOMETERS—(*Cont.*)

| Knots per Hour | Miles | Kilometers | Speed | | Knots per Hour | Miles | Kilometers | Speed | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Feet per Minute | Feet per Second | | | | Feet per Minute | Feet per Second |
| 18½ | 21.303 | 34.284 | 1874.7 | 31.24 | 29½ | 33.970 | 54.669 | 2989.3 | 49.82 |
| 18¾ | 21.591 | 34.747 | 1900. | 31.67 | 29¾ | 34.258 | 55.132 | 3014.7 | 50.24 |
| 19 | 21.879 | 35.211 | 1925.3 | 32.09 | 30 | 34.545 | 55.596 | 3040. | 50.67 |
| 19¼ | 22.167 | 35.674 | 1950.7 | 32.51 | 30¼ | 34.833 | 56.059 | 3065.3 | 51.09 |
| 19½ | 22.455 | 36.137 | 1976. | 32.93 | 30½ | 35.121 | 56.522 | 3090.7 | 51.51 |
| 19¾ | 22.742 | 36.600 | 2001.3 | 33.36 | 30¾ | 35.409 | 56.986 | 3116. | 51.93 |
| 20 | 23.030 | 37.064 | 2026.7 | 33.78 | 31 | 35.697 | 57.449 | 3141.3 | 52.36 |
| 20¼ | 23.318 | 37.527 | 2052. | 34.20 | 31¼ | 35.985 | 57.912 | 3166.7 | 52.78 |
| 20½ | 23.606 | 37.990 | 2077.3 | 34.62 | 31½ | 36.273 | 58.375 | 3192. | 53.20 |
| 20¾ | 23.894 | 38.454 | 2102.7 | 35.04 | 31¾ | 36.561 | 58.839 | 32[illegible]7.3 | 53.62 |
| 21 | 24.182 | 38.917 | 2128. | 35.47 | 32 | 36.848 | 59.302 | 3242.7 | 54.04 |
| 21¼ | 24.470 | 39.380 | 2153.3 | 35.89 | 32¼ | 37.136 | 59.765 | 3268. | 54.47 |
| 21½ | 24.758 | 39.844 | 2178.7 | 36.31 | 32½ | 37.424 | 60.229 | 3293.3 | 54.89 |
| 21¾ | 25.045 | 40.307 | 2204. | 36.73 | 32¾ | 37.712 | 60.692 | 3318.7 | 55.31 |
| 22 | 25.333 | 40.770 | 2229.3 | 37.16 | 33 | 38.000 | 61.155 | 3344. | 55.73 |
| 22¼ | 25.621 | 41.233 | 2254.7 | 37.58 | 33¼ | 38.288 | 61.618 | 3369.3 | 56.16 |
| 22½ | 25.909 | 41.697 | 2280. | 38.00 | 33½ | 38.576 | 62.082 | 3394.7 | 56.58 |
| 22¾ | 26.197 | 42.160 | 2305.3 | 38.42 | 33¾ | 38.864 | 62.545 | 3420. | 57.00 |
| 23 | 26.485 | 42.623 | 2330.7 | 38.84 | 34 | 39.152 | 63.008 | 3445.3 | 57.42 |
| 23¼ | 26.773 | 43.087 | 2356. | 39.27 | 34¼ | 39.439 | 63.472 | 3470.7 | 57.84 |
| 23½ | 27.061 | 43.550 | 2381.3 | 39.69 | 34½ | 39.727 | 63.935 | 3496. | 58.27 |
| 23¾ | 27.348 | 44.013 | 2406.7 | 40.11 | 34¾ | 40.015 | 64.398 | 3521.3 | 58.69 |
| 24 | 27.636 | 44.477 | 2432. | 40.53 | 35 | 40.303 | 64.862 | 3546.7 | 59.11 |
| 24¼ | 27.924 | 44.940 | 2457.3 | 40.96 | 35¼ | 40.591 | 65.325 | 3572. | 59.53 |
| 24½ | 28.212 | 45.403 | 2482.7 | 41.38 | 35½ | 40.879 | 65.788 | 3597.3 | 59.96 |
| 24¾ | 28.500 | 45.866 | 2508. | 41.80 | 35¾ | 41.167 | 66.251 | 3622.7 | 60.38 |
| 25 | 28.788 | 46.330 | 2533.3 | 42.22 | 36 | 41.455 | 66.715 | 3648. | 60.80 |
| 25¼ | 29.076 | 46.793 | 2558.7 | 42.64 | 36¼ | 41.742 | 67.178 | 3673.3 | 61.22 |
| 25½ | 29.364 | 47.256 | 2584. | 43.07 | 36½ | 42.030 | 67.641 | 3698.7 | 61.64 |
| 25¾ | 29.652 | 47.720 | 2609.3 | 43.49 | 36¾ | 42.318 | 68.105 | 3724. | 62.07 |
| 26 | 29.939 | 48.183 | 2634.7 | 43.91 | 37 | 42.606 | 68.568 | 3749.3 | 62.49 |
| 26¼ | 30.227 | 48.646 | 2660. | 44.33 | 37¼ | 42.894 | 69.031 | 3774.7 | 62.91 |
| 26½ | 30.515 | 49.109 | 2685.3 | 44.76 | 37½ | 43.182 | 69.495 | 3800. | 63.33 |
| 26¾ | 30.803 | 49.573 | 2710.7 | 45.18 | 37¾ | 43.470 | 69.958 | 3825.3 | 63.76 |
| 27 | 31.091 | 50.036 | 2736. | 45.60 | 38 | 43.758 | 70.421 | 3850.7 | 64.18 |
| 27¼ | 31.379 | 50.499 | 2761.3 | 46.02 | 38¼ | 44.045 | 70.884 | 3876. | 64.60 |
| 27½ | 31.667 | 50.963 | 2786.7 | 46.44 | 38½ | 44.333 | 71.348 | 3901.3 | 65.02 |
| 27¾ | 31.955 | 51.426 | 2812. | 46.87 | 38¾ | 44.621 | 71.811 | 3926.7 | 65.44 |
| 28 | 32.242 | 51.889 | 2837.3 | 47.29 | 39 | 44.909 | 72.274 | 3952. | 65.87 |
| 28¼ | 32.530 | 52.353 | 2862.7 | 47.71 | 39¼ | 45.197 | 72.738 | 3977.3 | 66.29 |
| 28½ | 32.818 | 52.815 | 2888. | 48.13 | 39½ | 45.485 | 73.201 | 4002.7 | 66.71 |
| 28¾ | 33.106 | 53.279 | 2913.3 | 48.56 | 39¾ | 45.773 | 73.664 | 4028. | 67.13 |
| 29 | 33.394 | 53.742 | 2938.7 | 48.98 | 40 | 46.061 | 74.128 | 4053.3 | 67.56 |
| 29¼ | 33.682 | 54.206 | 2964. | 49.40 | | | | | |

**Pressures. Pounds per Square Inch to Kilograms per Square Centimeter**

Conversion factor: 1 pound per square inch = 0.0703027 kilograms per square centimeter

| Pounds per Sq. In. | Kilograms per Sq. Cm. | Pounds per Sq. In. | Kilograms per Sq. Cm. | Pounds per Sq. In. | Kilograms per Sq. Cm. | Pounds per Sq. In. | Kilograms per Sq. Cm. |
|---|---|---|---|---|---|---|---|
| 0 | | 40 | 2.812 | 80 | 5.624 | 120 | 8.436 |
| 1 | .0703 | 1 | 2.882 | 1 | 5.695 | 1 | 8.507 |
| 2 | .1406 | 2 | 2.953 | 2 | 5.765 | 2 | 8.577 |
| 3 | .2109 | 3 | 3.023 | 3 | 5.835 | 3 | 8.647 |
| 4 | .2812 | 4 | 3.093 | 4 | 5.905 | 4 | 8.718 |
| 5 | .3515 | 5 | 3.164 | 5 | 5.976 | 5 | 8.788 |
| 6 | .4218 | 6 | 3.234 | 6 | 6.046 | 6 | 8.858 |
| 7 | .4921 | 7 | 3.304 | 7 | 6.116 | 7 | 8.928 |
| 8 | .5624 | 8 | 3.375 | 8 | 6.187 | 8 | 8.999 |
| 9 | .6327 | 9 | 3.445 | 9 | 6.257 | 9 | 9.069 |
| 10 | .703 | 50 | 3.515 | 90 | 6.327 | 130 | 9.139 |
| 1 | .773 | 1 | 3.585 | 1 | 6.398 | 1 | 9.210 |
| 2 | .844 | 2 | 3.656 | 2 | 6.468 | 2 | 9.280 |
| 3 | .914 | 3 | 3.726 | 3 | 6.538 | 3 | 9.350 |
| 4 | .984 | 4 | 3.796 | 4 | 6.608 | 4 | 9.421 |
| 5 | 1.055 | 5 | 3.867 | 5 | 6.679 | 5 | 9.491 |
| 6 | 1.125 | 6 | 3.937 | 6 | 6.749 | 6 | 9.561 |
| 7 | 1.195 | 7 | 4.007 | 7 | 6.819 | 7 | 9.631 |
| 8 | 1.265 | 8 | 4.078 | 8 | 6.890 | 8 | 9.702 |
| 9 | 1.336 | 9 | 4.148 | 9 | 6.960 | 9 | 9.772 |
| 20 | 1.406 | 60 | 4.218 | 100 | 7.030 | 140 | 9.842 |
| 1 | 1.476 | 1 | 4.288 | 1 | 7.101 | 1 | 9.913 |
| 2 | 1.547 | 2 | 4.359 | 2 | 7.171 | 2 | 9.983 |
| 3 | 1.617 | 3 | 4.429 | 3 | 7.241 | 3 | 10.053 |
| 4 | 1.687 | 4 | 4.499 | 4 | 7.311 | 4 | 10.124 |
| 5 | 1.758 | 5 | 4.570 | 5 | 7.382 | 5 | 10.194 |
| 6 | 1.828 | 6 | 4.640 | 6 | 7.452 | 6 | 10.264 |
| 7 | 1.898 | 7 | 4.710 | 7 | 7.522 | 7 | 10.334 |
| 8 | 1.968 | 8 | 4.781 | 8 | 7.593 | 8 | 10.405 |
| 9 | 2.039 | 9 | 4.851 | 9 | 7.663 | 9 | 10.475 |
| 30 | 2.109 | 70 | 4.921 | 110 | 7.733 | 150 | 10.545 |
| 1 | 2.179 | 1 | 4.991 | 1 | 7.804 | 1 | 10.616 |
| 2 | 2.250 | 2 | 5.062 | 2 | 7.874 | 2 | 10.686 |
| 3 | 2.320 | 3 | 5.132 | 3 | 7.944 | 3 | 10.756 |
| 4 | 2.390 | 4 | 5.202 | 4 | 8.015 | 4 | 10.827 |
| 5 | 2.461 | 5 | 5.273 | 5 | 8.085 | 5 | 10.897 |
| 6 | 2.531 | 6 | 5.343 | 6 | 8.155 | 6 | 10.967 |
| 7 | 2.601 | 7 | 5.413 | 7 | 8.225 | 7 | 11.038 |
| 8 | 2.672 | 8 | 5.484 | 8 | 8.296 | 8 | 11.108 |
| 9 | 2.742 | 9 | 5.554 | 9 | 8.366 | 9 | 11.178 |

PRESSURES. POUNDS PER SQUARE INCH TO KILOGRAMS PER SQUARE CENTIMETER—(*Cont.*)

| Pounds per Sq. In. | Kilograms per Sq. Cm. | Pounds per Sq. In. | Kilograms per Sq. Cm. | Pounds per Sq. In. | Kilograms per Sq. Cm. | Pounds per Sq. In. | Kilograms per Sq. Cm. |
|---|---|---|---|---|---|---|---|
| 160 = | 11.248 | 200 = | 14.061 | 240 = | 16.873 | 280 = | 19.685 |
| 1 = | 11.319 | 1 = | 14.131 | 1 = | 16.943 | 1 = | 19.755 |
| 2 = | 11.389 | 2 = | 14.201 | 2 = | 17.013 | 2 = | 19.825 |
| 3 = | 11.459 | 3 = | 14.271 | 3 = | 17.084 | 3 = | 19.896 |
| 4 = | 11.530 | 4 = | 14.342 | 4 = | 17.154 | 4 = | 19.966 |
| 5 = | 11.600 | 5 = | 14.412 | 5 = | 17.224 | 5 = | 20.036 |
| 6 = | 11.670 | 6 = | 14.482 | 6 = | 17.294 | 6 = | 20.107 |
| 7 = | 11.741 | 7 = | 14.553 | 7 = | 17.365 | 7 = | 20.177 |
| 8 = | 11.811 | 8 = | 14.623 | 8 = | 17.435 | 8 = | 20.247 |
| 9 = | 11.881 | 9 = | 14.693 | 9 = | 17.505 | 9 = | 20.317 |
| 170 = | 11.951 | 210 = | 14.764 | 250 = | 17.576 | 290 = | 20.388 |
| 1 = | 12.022 | 1 = | 14.834 | 1 = | 17.646 | 1 = | 20.458 |
| 2 = | 12.092 | 2 = | 14.904 | 2 = | 17.716 | 2 = | 20.528 |
| 3 = | 12.162 | 3 = | 14.974 | 3 = | 17.787 | 3 = | 20.599 |
| 4 = | 12.233 | 4 = | 15.045 | 4 = | 17.857 | 4 = | 20.669 |
| 5 = | 12.303 | 5 = | 15.115 | 5 = | 17.927 | 5 = | 20.739 |
| 6 = | 12.373 | 6 = | 15.185 | 6 = | 17.997 | 6 = | 20.810 |
| 7 = | 12.444 | 7 = | 15.256 | 7 = | 18.068 | 7 = | 20.880 |
| 8 = | 12.514 | 8 = | 15.326 | 8 = | 18.138 | 8 = | 20.950 |
| 9 = | 12.584 | 9 = | 15.396 | 9 = | 18.208 | 9 = | 21.021 |
| 180 = | 12.654 | 220 = | 15.467 | 260 = | 18.279 | 300 = | 21.091 |
| 1 = | 12.725 | 1 = | 15.537 | 1 = | 18.349 | 400 = | 28.121 |
| 2 = | 12.795 | 2 = | 15.607 | 2 = | 18.419 | 500 = | 35.151 |
| 3 = | 12.865 | 3 = | 15.678 | 3 = | 18.490 | 600 = | 42.182 |
| 4 = | 12.936 | 4 = | 15.748 | 4 = | 18.560 | 700 = | 49.212 |
| 5 = | 13.006 | 5 = | 15.818 | 5 = | 18.630 | 800 = | 56.242 |
| 6 = | 13.076 | 6 = | 15.888 | 6 = | 18.701 | 900 = | 63.272 |
| 7 = | 13.147 | 7 = | 15.959 | 7 = | 18.771 | 1000 = | 70.303 |
| 8 = | 13.217 | 8 = | 16.029 | 8 = | 18.841 | 1100 = | 77.333 |
| 9 = | 13.287 | 9 = | 16.099 | 9 = | 18.911 | 1200 = | 84.363 |
| 190 = | 13.358 | 230 = | 16.170 | 270 = | 18.982 | 1300 = | 91.393 |
| 1 = | 13.428 | 1 = | 16.240 | 1 = | 19.052 | 1400 = | 98.424 |
| 2 = | 13.498 | 2 = | 16.310 | 2 = | 19.122 | 1500 = | 105.454 |
| 3 = | 13.568 | 3 = | 16.381 | 3 = | 19.193 | 1600 = | 112.484 |
| 4 = | 13.639 | 4 = | 16.451 | 4 = | 19.263 | 1700 = | 119.515 |
| 5 = | 13.709 | 5 = | 16.521 | 5 = | 19.333 | 1800 = | 126.545 |
| 6 = | 13.779 | 6 = | 16.591 | 6 = | 19.404 | 1900 = | 133.575 |
| 7 = | 13.850 | 7 = | 16.662 | 7 = | 19.474 | 2000 = | 140.605 |
| 8 = | 13.920 | 8 = | 16.732 | 8 = | 19.544 | 2100 = | 147.636 |
| 9 = | 13.990 | 9 = | 16.802 | 9 = | 19.614 | 2200 = | 154.666 |

### Speed or Flow. Cubic Feet per Second to Cubic Meters per Second

Reduction factor: 1 cubic foot per second = 0.0283170 cubic meter per second

| Cubic Feet per Second | Cubic Meters per Second | Cubic Feet per Second | Cubic Meters per Second | Cubic Feet per Second | Cubic Meters per Second | Cubic Feet per Second | Cubic Meters per Second | Cubic Feet per Second | Cubic Meters per Second |
|---|---|---|---|---|---|---|---|---|---|
| 0 | | 40 = | 1.133 | 80 = | 2.265 | 300 = | 8.495 | 700 = | 19.822 |
| 1 = | .028 | 1 = | 1.161 | 1 = | 2.294 | 310 = | 8.778 | 710 = | 20.105 |
| 2 = | .057 | 2 = | 1.189 | 2 = | 2.322 | 320 = | 9.061 | 720 = | 20.388 |
| 3 = | .085 | 3 = | 1.218 | 3 = | 2.350 | 330 = | 9.345 | 730 = | 20.671 |
| 4 = | .113 | 4 = | 1.246 | 4 = | 2.379 | 340 = | 9.628 | 740 = | 20.955 |
| 5 = | .142 | 5 = | 1.274 | 5 = | 2.407 | 350 = | 9.911 | 750 = | 21.238 |
| 6 = | .170 | 6 = | 1.303 | 6 = | 2.435 | 360 = | 10.194 | 760 = | 21.521 |
| 7 = | .198 | 7 = | 1.331 | 7 = | 2.464 | 370 = | 10.477 | 770 = | 21.804 |
| 8 = | .227 | 8 = | 1.359 | 8 = | 2.492 | 380 = | 10.760 | 780 = | 22.087 |
| 9 = | .255 | 9 = | 1.388 | 9 = | 2.520 | 390 = | 11.044 | 790 = | 22.370 |
| 10 = | .283 | 50 = | 1.416 | 90 = | 2.549 | 400 = | 11.327 | 800 = | 22.654 |
| 1 = | .311 | 1 = | 1.444 | 1 = | 2.577 | 410 = | 11.610 | 810 = | 22.937 |
| 2 = | .340 | 2 = | 1.472 | 2 = | 2.605 | 420 = | 11.893 | 820 = | 23.220 |
| 3 = | .368 | 3 = | 1.500 | 3 = | 2.633 | 430 = | 12.176 | 830 = | 23.503 |
| 4 = | .396 | 4 = | 1.529 | 4 = | 2.662 | 440 = | 12.459 | 840 = | 23.786 |
| 5 = | .425 | 5 = | 1.557 | 5 = | 2.690 | 450 = | 12.743 | 850 = | 24.069 |
| 6 = | .453 | 6 = | 1.586 | 6 = | 2.718 | 460 = | 13.026 | 860 = | 24.353 |
| 7 = | .481 | 7 = | 1.614 | 7 = | 2.747 | 470 = | 13.309 | 870 = | 24.636 |
| 8 = | .510 | 8 = | 1.642 | 8 = | 2.775 | 480 = | 13.592 | 880 = | 24.919 |
| 9 = | .538 | 9 = | 1.671 | 9 = | 2.803 | 490 = | 13.875 | 890 = | 25.202 |
| 20 = | .566 | 60 = | 1.699 | 100 = | 2.832 | 500 = | 14.159 | 900 = | 25.485 |
| 1 = | .595 | 1 = | 1.727 | 110 = | 3.115 | 510 = | 14.442 | 910 = | 25.768 |
| 2 = | .623 | 2 = | 1.756 | 120 = | 3.398 | 520 = | 14.725 | 920 = | 26.052 |
| 3 = | .651 | 3 = | 1.784 | 130 = | 3.681 | 530 = | 15.008 | 930 = | 26.335 |
| 4 = | .680 | 4 = | 1.812 | 140 = | 3.964 | 540 = | 15.291 | 940 = | 26.618 |
| 5 = | .708 | 5 = | 1.841 | 150 = | 4.248 | 550 = | 15.574 | 950 = | 26.901 |
| 6 = | .736 | 6 = | 1.869 | 160 = | 4.531 | 560 = | 15.858 | 960 = | 27.184 |
| 7 = | .765 | 7 = | 1.897 | 170 = | 4.814 | 570 = | 16.141 | 970 = | 27.467 |
| 8 = | .793 | 8 = | 1.926 | 180 = | 5.097 | 580 = | 16.424 | 980 = | 27.751 |
| 9 = | .821 | 9 = | 1.954 | 190 = | 5.380 | 590 = | 16.707 | 990 = | 28.034 |
| 30 = | .850 | 70 = | 1.982 | 200 = | 5.663 | 600 = | 16.990 | 1000 = | 28.317 |
| 1 = | .878 | 1 = | 2.011 | 210 = | 5.947 | 610 = | 17.273 | 2000 = | 56.634 |
| 2 = | .906 | 2 = | 2.039 | 220 = | 6.230 | 620 = | 17.557 | 3000 = | 84.951 |
| 3 = | .934 | 3 = | 2.067 | 230 = | 6.513 | 630 = | 17.840 | 4000 = | 113.268 |
| 4 = | .963 | 4 = | 2.095 | 240 = | 6.796 | 640 = | 18.123 | 5000 = | 141.585 |
| 5 = | .991 | 5 = | 2.124 | 250 = | 7.079 | 650 = | 18.406 | | |
| 6 = | 1.019 | 6 = | 2.152 | 260 = | 7.362 | 660 = | 18.689 | | |
| 7 = | 1.048 | 7 = | 2.180 | 270 = | 7.646 | 670 = | 18.972 | | |
| 8 = | 1.076 | 8 = | 2.209 | 280 = | 7.929 | 680 = | 19.256 | | |
| 9 = | 1.104 | 9 = | 2.237 | 290 = | 8.212 | 690 = | 19.539 | | |

# WIRE GAUGES

## BUREAU OF STANDARDS

Wire gauges are in use now less than formerly, two only are used extensively in this country, viz., the "American Wire Gauge" (Brown & Sharpe) and the "Steel Wire Gauge" (variously called the Washburn & Moen, Roebling, and American Steel & Wire Company's). Three other gauges are still used to some extent, viz., the Birmingham Wire Gauge (Stubs), the Old English Wire Gauge (London), and the Stubs' Steel Wire Gauge. There are in addition certain special gauges, such as the Music Wire Gauge, the drill and screw gauges, and the United States Standard Sheet-Metal Gauge. In England one wire gauge has been made legal and is in use generally, viz., the "Standard Wire Gauge." The diameters of the six general wire gauges mentioned are given in mils in Table 4, and in millimeters in Table 5. In Germany, France, Austria, Italy, and other continental countries practically no wire gauge is used; size of wires is specified directly by the diameter in millimeters. This system is sometimes called the "millimeter wire gauge."

**The American Wire Gauge** was devised by J. R. Brown, one of the founders of the Brown & Sharpe Manufacturing Co., in 1857. It speedily superseded the Birmingham Wire Gauge in this country, which was then in general use. It is, perhaps, more generally known by the name "Brown & Sharpe Gauge," but this name is not the one preferred by the Brown & Sharpe Co. In their catalogues they regularly refer to the gauge as the "American Standard Wire Gauge." The word "Standard" is probably not a good one to retain in the name of this gauge, since it is not the standard gauge for all metals in the United States; and, further, since it is not a legalized gauge, as are the (British) Standard Wire Gauge and the United States Standard Sheet-Metal Gauge. The abbreviation for the name of this gauge has usually been written "A. W. G." The American Wire Gauge is now used for more metals than any other in this country, and is practically the only gauge used for copper and aluminum wire, and in general for wire used in electrical work. It is the only wire gauge now in use whose successive sizes are determined by a simple mathematical law.

**Characteristics of the American Wire Gauge.**—The gauge is formed by the specification of two diameters and the law that a given number of intermediate diameters are formed by geometrical progression. Thus, the diameter of No. 0000 is defined as 0.4600 inch and of No. 36 as 0.0050 inch. There are 38 sizes between these two, hence the ratio of any diameter to the diameter of the next greater number $= \sqrt[39]{\frac{.4600}{.0050}} = \sqrt[39]{92} = 1.122\,932\,2$. The square of this ratio = 1.2610. The sixth power of the ratio, i.e., the ratio of any diameter to the diameter of the sixth greater number = 2.0050.

The law of geometrical progression on which the gauge is based may be expressed in either of the three following manners: (1) the ratio of any diameter to the next smaller is a constant number; (2) the difference between any two successive diameters is a constant per cent of the smaller of the two diameters; (3) the difference between any two successive diameters is a constant ratio times the next smaller difference between two successive diameters.

**The " Steel Wire Gauge "** is the same gauge which has been known by the names of Washburn & Moen gauge and American Steel & Wire Co.'s gauge. This gauge also, with a number of its sizes rounded off to thousandths of an inch, has been known as the Roebling gauge. The gauge was established by Ichabod Washburn about the year 1830, and was named after the Washburn & Moen Manufacturing Co. This company is no longer in existence, having been merged into the American Steel & Wire Co. The latter company continued the use of the Washburn & Moen Gauge for steel wire, giving it the name "American Steel & Wire Co.'s gauge." The company specifies all steel wire by this gauge, and states that it is used for fully 85 per cent of the total

production of steel wire. This gauge was also formerly used by the John A. Roebling's Sons Co., who named it the Roebling gauge, as mentioned above. However, the Roebling company, who are engaged in the production of wire for electrical purposes, now prefer to use the American Wire Gauge.

The name "Steel Wire Gauge" was suggested by the Bureau of Standards, in its correspondence with various companies, and it met with practically unanimous approval. It was necessary to decide upon a name for this gauge, and the three names which have been used for it in the past were all open to the objection that they were the names of particular companies. These companies have accepted the new name. The abbreviations of the name of the gauge should be "Stl. W. G.," to distinguish it from "S. W. G." the abbreviation for the (British) Standard Wire Gauge. When it is necessary to distinguish the name of this gauge from others which may be used for steel wire, e.g., the (British) Standard Wire Gauge, it may be called the United States Steel Wire Gauge.

**Decimal Measurement.**—The trend of practice in the gaging of materials is increasingly toward the direct specification of the dimensions in decimal fractions of an inch, without use of gauge numbers. This has been, for a number of years, the practice of some of the large electrical and manufacturing companies of this country. The United States Navy Department also, in June, 1911, ordered that all diameters and thicknesses of materials be specified directly in decimal fractions of an inch, omitting all reference to gauge numbers. The War Department, in December, 1911, issued a similar order, for all wires. The American Society for Testing Materials, in their Specifications for Copper Wire, recommend that diameters instead of gauge numbers be used. This is similar to the practice on the Continent of Europe, where sizes of wire are specified directly by the diameters in millimeters. The practice of specifying the diameters themselves and omitting gauge numbers has the advantages that it avoids possible confusion with other gauge systems and states an actual property of the wire directly.

**Stock Sizes of Wire.**—When gauge numbers are not used, it is necessary that a certain set of stock sizes be considered standard, so that the manufacturers would not be required to keep in stock an unduly large number of different sizes of wire. The large companies who have ceased to use gauge numbers have recognized this, having taken as standard the American Wire Gauge sizes, to the nearest mil, for the larger diameters and to a tenth of a mil for the smaller. (See list of sizes, Table IV.) These sizes were adopted, in December, 1911, by the United States War Department for all wires. It seems likely that this system of sizes, based on the American Wire Gauge, will be perpetuated.

**Micrometer Gauges.**—The objection is often raised that the use of diameters requires the employment of a micrometer; and that the wire gauge as an instrument marked in gauge numbers is a very rapid means of handling wires and is indispensable for use by unskilled workmen. However, the use of the wire gauge as an instrument is consistent with the practice of specifying the diameters directly, provided the wire gauge is marked in mils. Wire gauges marked both in the A. W. G. numbers and in thousandths of an inch can be obtained from the manufacturers. One thus reads off directly from the wire gauge 81 mil, 64 mil, etc., just as he would No. 12, No. 14, etc. (Of course, the diameters in millimeters could be marked on the gauge for those who prefer the metric system.) It should not be forgotten, however, that a wire gauge gradually wears with use, and that for accurate work a micrometer should always be used.

**Birmingham Wire Gauge.**—Of the three wire gauges which have remained in use but are now nearly obsolete, the one most frequently mentioned is the Birmingham, sometimes called the Stubs' Wire Gauge. Its numbers were based upon the reduction of size made in practice by drawing wire from rolled rod. Thus, rod was called No. 0, first drawing No. 1, and so on. Its gradations of size are very irregular, as shown in the table of "Wire Gauges in Use in the United States," given on the page following; by simply comparing the several decimal equivalents of the Birmingham gauge with the equivalents of the American, or Brown & Sharpe gauge, as they appear directly opposite in the first column of the table. The Birmingham gauge is typical of most wire gauges, and the irregularity of its steps is shown in marked contrast to the

regularity of the steps of the American Wire Gauge. The Birmingham gauge was used extensively both in Great Britain and in the United States for many years. It has been superseded, however, and is now nearly obsolete.

The principal outstanding exception to the abandonment of the Birmingham gauge is that the Treasury Department, with certain legislative sanction, still specifies the Birmingham gauge for use in the collection of duty on imports of wire. This gauge was prescribed by the Treasury Department in 1875, after it had been ascertained that it was the standard gauge "not only throughout the United States, but the world." This reason for the use of this gauge does not now exist, inasmuch as the gauge is now used very little in the United States, and even less in other countries, but the Treasury Department considers that it can not change its practice, since legislative approval has been given the Birmingham gauge by the tariff acts with a provision for assessment of duty according to gauge numbers, and further since a change would alter the rate of duty on certain sizes of wire. These facts have been brought to the attention of the congressional committees which have charge of tariff legislation, and it is possible that when the tariff act is next amended the gauge numbers will be stricken out and the diameters themselves specified.

**The Stubs' Steel Wire Gauge** has a somewhat limited use for tool steel wire and drill rods. This gauge should not be confused with the Birmingham, which is sometimes known as Stubs' Iron Wire Gauge.

**English Standard.**—The "Standard Wire Gauge," otherwise known as the New British Standard, the English Legal Standard, or the Imperial Wire Gauge, is the legal standard of Great Britain for all wires, as fixed by order in Council, August 23, 1883. It was constructed by modifying the Birmingham Wire Gauge, so that the differences between successive diameters were the same for short ranges, i.e., so that a graph representing the diameters consists of a series of a few straight lines.

WIRE GAUGES IN USE IN THE UNITED STATES

Dimensions are in decimal parts of an inch

| Number of Wire Gauge | American or Brown & Sharpe | Birmingh'm or Stubs' Iron Wire | Steel Wire Gauge: Washburn & Moen / Roebling / American Steel & Wire Co. | British Imperial Wire Gauge S. W. G. | Stubs' Steel Wire | United States Standard for Plate |
|---|---|---|---|---|---|---|
| 0000000 | ...... | .... | .4900 | .500 | .... | .500 |
| 000000 | .58000 | .... | .4615 | .464 | .... | .46875 |
| 00000 | .51650 | .... | .4305 | .432 | .... | .4375 |
| 0000 | .46000 | .454 | .3938 | .400 | .... | .40625 |
| 000 | .40964 | .425 | .3625 | .372 | .... | .375 |
| 00 | .36480 | .38 | .3310 | .348 | .... | .34375 |
| 0 | .32486 | .34 | .3065 | .324 | .... | .3125 |
| 1 | .28930 | .3 | .2830 | .300 | .227 | .28125 |
| 2 | .25763 | .284 | .2625 | .276 | .219 | .265625 |
| 3 | .22942 | .259 | .2437 | .252 | .212 | .25 |
| 4 | .20431 | .238 | .2253 | .232 | .207 | .234375 |
| 5 | .18194 | .22 | .2070 | .212 | .204 | .21875 |
| 6 | .16202 | .203 | .1920 | .192 | .201 | .203125 |
| 7 | .14428 | .18 | .1770 | .176 | .199 | .1875 |
| 8 | .12849 | .165 | .1620 | .160 | .197 | .171875 |
| 9 | .11443 | .148 | .1483 | .144 | .194 | .15625 |

WIRE GAUGES IN USE IN THE UNITED STATES—(*Cont.*,

| Number of Wire Gauge | American or Brown & Sharpe | Birmingh'm or Stubs' Iron Wire | Steel Wire Gauge: Washburn & Moen / Roebling / American Steel & Wire Co. | British Imperial Wire Gauge S. W. G. | Stubs' Steel Wire | United States Standard for Plate |
|---|---|---|---|---|---|---|
| 10 | .101897 | .134 | .1350 | .128 | .191 | .140625 |
| 11 | .090742 | .12 | .1205 | .116 | .188 | .125 |
| 12 | .080808 | .109 | .1055 | .104 | .185 | .109375 |
| 13 | .071961 | .095 | .0915 | .092 | .182 | .09375 |
| 14 | .064084 | .083 | .0800 | .080 | .180 | .078125 |
| 15 | .057068 | .072 | .0720 | .072 | .178 | .0703125 |
| 16 | .050821 | .065 | .0625 | .064 | .175 | .0625 |
| 17 | .045257 | .058 | .0540 | .056 | .172 | .05625 |
| 18 | .040303 | .049 | .0475 | .048 | .168 | .05 |
| 19 | .035890 | .042 | .0410 | .040 | .164 | .04375 |
| 20 | .031961 | .035 | .0348 | .036 | .161 | .0375 |
| 21 | .028462 | .032 | .03175 | .032 | .157 | .034375 |
| 22 | .025347 | .028 | .0286 | .028 | .155 | .03125 |
| 23 | .022571 | .025 | .0258 | .024 | .153 | .028125 |
| 24 | .020101 | .022 | .0230 | .022 | .151 | .025 |
| 25 | .017900 | .02 | .0204 | .020 | .148 | .021875 |
| 26 | .015941 | .018 | .0181 | .018 | .146 | .01875 |
| 27 | .014195 | .016 | .0173 | .0164 | .143 | .0171875 |
| 28 | .012641 | .014 | .0162 | .0149 | .139 | .015625 |
| 29 | .011257 | .013 | .0150 | .0136 | .134 | .0140625 |
| 30 | .010025 | .012 | .0140 | .0124 | .127 | .0125 |
| 31 | .008928 | .01 | .0132 | .0116 | .120 | .0109375 |
| 32 | .007950 | .009 | .0128 | .0108 | .115 | .01015625 |
| 33 | .007080 | .008 | .0118 | .0100 | .112 | .009375 |
| 34 | .006304 | .007 | .0104 | .0092 | .110 | .00859375 |
| 35 | .005614 | .005 | .0095 | .0084 | .108 | .0078125 |
| 36 | .005000 | .004 | .0090 | .0076 | .106 | .00703125 |
| 37 | .004453 | .... | .0085 | .0068 | .103 | .006640625 |
| 38 | .003965 | .... | .0080 | .0060 | .101 | .00625 |
| 39 | .003531 | .... | .0075 | .0052 | .099 | .......... |
| 40 | .003144 | .... | .0070 | .0048 | .097 | .......... |

NOTE.—Reference to Tables 4 and 5, page 69, are Copper Wire Tables issued by the Bureau of Standards. These tables will be found in the Electrical Section of this book. When it is remembered that a *mil* is a unit of length used in measuring the diameter of wire equal to one thousandth of an inch, it is only necessary when diameters are given in decimal parts of an inch to move the decimal point to correspond, thus, reading across the table given above: No. 1 American wire gauge is .28930 inch diameter, or 289 *mils*. No. 1 Birmingham gauge = .3 inch diameter, or 300 *mils*. No. 1 Steel wire gauge = .2830 inch diameter, or 283 *mils*.

# U. S. STANDARD GAUGE FOR SHEET AND PLATE IRON AND STEEL

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That for the purpose of securing uniformity, the following is established as the only standard gauge for sheet and plate iron and steel in the United States of America, namely:

| Number of Gauge | Approximate Thickness, in Fractions of an Inch | Approximate Thickness, in Decimal Parts of an Inch | Approximate Thickness, in Millimeters | Weight per Square Foot, in Ounces Avoirdupois | Weight per Square Foot, in Pounds Avoirdupois | Weight per Square Foot, in Kilograms | Weight per Square Meter, in Kilograms | Weight per Square Meter, in Pounds Avoirdupois |
|---|---|---|---|---|---|---|---|---|
| 0000000 | 1-2 | .5 | 12.7 | 320 | 20.00 | 9.072 | 97.65 | 215.28 |
| 000000 | 15-32 | .46875 | 11.90625 | 300 | 18.75 | 8.505 | 91.55 | 201.82 |
| 00000 | 7-16 | .4375 | 11.1125 | 280 | 17.50 | 7.983 | 85.44 | 188.37 |
| 0000 | 13-32 | .40625 | 10.31875 | 260 | 16.25 | 7.371 | 79.33 | 174.91 |
| 000 | 3-8 | .375 | 9.525 | 240 | 15 | 6.804 | 73.24 | 161.46 |
| 00 | 11-32 | .34375 | 8.73125 | 220 | 13.75 | 6.237 | 67.13 | 148.00 |
| 0 | 5-16 | .3125 | 7.9375 | 200 | 12.50 | 5.67 | 61.03 | 134.55 |
| 1 | 9-32 | .28125 | 7.14375 | 180 | 11.25 | 5.103 | 54.93 | 121.09 |
| 2 | 17-64 | .265625 | 6.746875 | 170 | 10.625 | 4.819 | 51.88 | 114.37 |
| 3 | 1-4 | .25 | 6.35 | 160 | 10 | 4.536 | 48.82 | 107.64 |
| 4 | 15-64 | .234375 | 5.953125 | 150 | 9.375 | 4.252 | 45.77 | 100.91 |
| 5 | 7-32 | .21875 | 5.55625 | 140 | 8.75 | 3.969 | 42.72 | 94.18 |
| 6 | 13-64 | .203125 | 5.159375 | 130 | 8.125 | 3.685 | 39.67 | 87.45 |
| 7 | 3-16 | .1875 | 4.7625 | 120 | 7.5 | 3.402 | 36.62 | 80.72 |
| 8 | 11-64 | .171875 | 4.365625 | 110 | 6.875 | 3.118 | 33.57 | 74.00 |
| 9 | 5-32 | .15625 | 3.96875 | 100 | 6.25 | 2.835 | 30.52 | 67.27 |
| 10 | 9-64 | .140625 | 3.571875 | 90 | 5.625 | 2.552 | 27.46 | 60.55 |
| 11 | 1-8 | .125 | 3.175 | 80 | 5 | 2.268 | 24.41 | 53.82 |
| 12 | 7-64 | .109375 | 2.778125 | 70 | 4.375 | 1.984 | 21.36 | 47.09 |
| 13 | 3-32 | .09375 | 2.38125 | 60 | 3.75 | 1.701 | 18.31 | 40.36 |
| 14 | 5-64 | .078125 | 1.984375 | 50 | 3.125 | 1.417 | 15.26 | 33.64 |
| 15 | 9-128 | .0703125 | 1.7859375 | 45 | 2.8125 | 1.276 | 13.73 | 30.27 |
| 16 | 1-16 | .0625 | 1.5875 | 40 | 2.5 | 1.134 | 12.21 | 26.91 |
| 17 | 9-160 | .05625 | 1.42875 | 36 | 2.25 | 1.021 | 10.99 | 24.22 |
| 18 | 1-20 | .05 | 1.27 | 32 | 2 | .9072 | 9.765 | 21.53 |
| 19 | 7-160 | .04375 | 1.11125 | 28 | 1.75 | .7988 | 8.544 | 18.84 |
| 20 | 3-80 | .0375 | .9525 | 24 | 1.50 | .6804 | 7.324 | 16.15 |
| 21 | 11-320 | .034375 | .873125 | 22 | 1.375 | .6237 | 6.713 | 14.80 |
| 22 | 1-32 | .03125 | .793750 | 20 | 1.25 | .567 | 6.103 | 13.46 |
| 23 | 9-320 | .028125 | .714375 | 18 | 1.125 | .5103 | 5.493 | 12.11 |
| 24 | 1-40 | .025 | .635 | 16 | 1 | .4536 | 4.882 | 10.76 |
| 25 | 7-320 | .021875 | .555625 | 14 | .875 | .3969 | 4.272 | 9.42 |
| 26 | 3-160 | .01875 | .47625 | 12 | .75 | .3402 | 3.662 | 8.07 |
| 27 | 11-640 | .0171875 | .4365625 | 11 | .6875 | .3119 | 3.357 | 7.40 |
| 28 | 1-64 | .015625 | .396875 | 10 | .625 | .2835 | 3.052 | 6.73 |

U. S. Standard Gauge for Sheet and Plate Iron and Steel—(*Cont.*)

| Number of Gauge | Approximate Thickness, in Fractions of an Inch | Approximate Thickness, in Decimal Parts of an Inch | Approximate Thickness, in Millimeters | Weight per Square Foot, in Ounces Avoirdupois | Weight per Square Foot, in Pounds Avoirdupois | Weight per Square Foot, in Kilograms | Weight per Square Meter, in Kilograms | Weight per Square Meter, in Pounds Avoirdupois |
|---|---|---|---|---|---|---|---|---|
| 29 | 9-640 | .0140625 | .3571875 | 9 | .5625 | .2551 | 2.746 | 6.05 |
| 30 | 1-80 | .0125 | .3175 | 8 | .5 | .2268 | 2.441 | 5.38 |
| 31 | 7-640 | .0109375 | .2778125 | 7 | .4375 | .1984 | 2.136 | 4.71 |
| 32 | 13-1280 | .01015625 | .25796875 | 6½ | .40625 | .1843 | 1.983 | 4.37 |
| 33 | 3-320 | .009375 | .238125 | 6 | .375 | .1701 | 1.831 | 4.04 |
| 34 | 11-1280 | .00859375 | .21828125 | 5½ | .34375 | .1559 | 1.678 | 3.70 |
| 35 | 5-640 | .0078125 | .1984375 | 5 | .3125 | 1.417 | 1.526 | 3.36 |
| 36 | 9-1280 | .00703125 | .17859375 | 4½ | .28125 | .1276 | 1.373 | 3.03 |
| 37 | 17-2560 | .006640625 | .168671875 | 4¼ | .265625 | .1205 | 1.297 | 2.87 |
| 38 | 1-160 | .00625 | .15875 | 4 | .25 | .1134 | 1.221 | 2.69 |

And on and after July 1, 1893, the same and no other shall be used in determining duties and taxes levied by the United States of America on sheet and plate iron and steel. But this act shall not be construed to increase duties upon any articles which may be imported.

Sec. 2. That the Secretary of the Treasury is authorized and required to prepare suitable standards in accordance herewith.

Sec. 3. That in the practical use and application of the standard gauge hereby established a variation of 2½ per cent either way may be allowed.

Approved, March 3, 1893.

Note.—A variation of 2½ per cent either way is permitted, so that the excessive number of decimal places in the "approximate" equivalents is undue refinement for the practical purposes for which the act was established. Moreover, the values in some cases are beyond the limits of measurement of the highest precision. For these reasons and greater convenience in use, the figures not usually required in view of the tolerance are printed in smaller type.

S. W. Stratton,
Director Bureau of Standards.

# LEGAL WEIGHTS (IN POUNDS) PER BUSHEL OF VARIOUS COMMODITIES

## BUREAU OF STANDARDS

**I. Introduction.**—The legal weights per bushel of various commodities, as given in the following tables, have been fixed by national legislation mainly for customs purposes or by the State legislatures for purposes of commerce within the States. In many cases these weights differ considerably in the different States, and in the cases of only a few commodities, such as wheat, oats, and pease, are the legal weights uniform throughout the entire country. It should not be assumed that the legal weights herein given represent a volume equal to the bushel of 2,150.42 cubic inches (United States bushel). On account of the variations in the densities of commodities in different localities and in different seasons, it is impossible to fix with any degree of certainty the weight of a given volume. The best that could be done would be to give the average of all localities for a number of years. Inasmuch, however, as the weight of a given volume of any commodity, such as potatoes, apples, coal, corn, etc., can only be approximately fixed, it is important in transactions involving such measures that it be distinctly understood which bushel is meant, viz., the volume of 2,150.42 cubic inches or a certain number of pounds called a bushel, which might be quite a different amount. On account of the impossibility of reconciling these two definitions of the bushel, it is recommended that all sales be made by weight, as is now the practice in wheat transactions.

### II. Commodities for Which Bushel Weights Have Been Adopted in But One or Two States

Alsike (or Swedish) seed, 60 pounds (Md. and Okla.).

Beggarweed seed, 62 pounds (Fla.).
Bermuda grass seed, 40 pounds (Okla.).
Blackberries, 30 pounds (Iowa); 48 pounds (Tenn.); dried, 28 pounds (Tenn.).
Blueberries, 42 pounds (Minn.).
Bromus inermus, 14 pounds (N. Dak.).
Burr clover, in hulls, 8 pounds (N. C.).

Cabbage, 50 pounds (Tenn.).
Canary seed, 60 pounds (Tenn.); 50 pounds (Iowa).
Cantaloupe melon, 50 pounds (Tenn.).
Caster seed, 50 pounds (Md.).
Cement, 80 pounds (Tenn.).
Cherries, 40 pounds (Iowa); with stems, 56 pounds (Tenn.); without stems, 64 pounds (Tenn.).
Chufa, 54 pounds (Fla.).
Cotton seed, staple, 42 pounds (S. C.).
Culm, 80 pounds (Md.).
Currants, 40 pounds (Iowa and Minn.).

Feed, 50 pounds (Mass.).
Fescue, seed of all the, except the tall and meadow fescue, 14 pounds (N. C.).
Fescue, tall and meadow fescue grass seed, 24 pounds (N. C.).
Grapes, 40 pounds (Iowa); with stems, 48 pounds (Tenn.); without stems, 60 pounds (Tenn.).
Guavas, 54 pounds (Fla.).

Hominy, 60 pounds (Ohio); 62 pounds (Tenn.).
Horseradish, 50 pounds (Tenn.).

Italian rye-grass seed, 20 pounds (Tenn.).

Japan clover in hulls, 25 pounds (N. C.).
Johnson grass, 28 pounds (Ark.); 25 pounds (N. C.).

Kale, 30 pounds (Tenn.).

Land plaster, 100 pounds (Tenn.).
Lentils, 60 pounds (N. C.).
Lucerne, 60 pounds (N. C.).
Lupines, 60 pounds (N. C.).

Meadow seed, tall, 14 pounds (N. C.).
Meal (?), 46 pounds (Ala.); unbolted, 48 pounds (Ala.).
Middlings, fine, 40 pounds (Ind.); coarse middlings, 30 pounds (Ind.).

Millet, Japanese barnyard, 35 pounds (Mass. and N. H.).
Mustard, 30 pounds (Tenn.).
Mustard seed, 58 pounds (N. C.).

Oat grass seed, 14 pounds (N. C.).

Plums, 40 pounds (Fla.); 64 pounds (Tenn.); dried, 28 pounds (Mich.).
Prunes, dried, 28 pounds (Idaho); green, 45 pounds (Idaho).

Radish seed, 50 pounds (Iowa).
Raspberries, 32 pounds (Iowa and Kan.); 48 pounds (Tenn.).
Rhubarb, 50 pounds (Tenn.).

Sage, 4 pounds (Tenn.).
Salads, 30 pounds (Tenn.).
Sand, 130 pounds (Iowa).
Seed of brome grasses, 14 pounds (N. C.).
Spinach, 30 pounds (Tenn.).
Strawberries, 32 pounds (Iowa); 48 pounds (Tenn.).
Sugar cane seed (amber), 57 pounds (N. J.).
Sunflower seed, 24 pounds (N. C.).

Teosinte, 59 pounds (N. C.).

Velvet grass seed, 7 pounds (Tenn.).
Vetches, 60 pounds (N. C.).

In the following pages is given an alphabetical list of commodities for which legal weights (in pounds) per bushel have been more generally adopted by States. Special explanations or conditions affecting the definition are printed in foot-notes to these tables.

## Legal Weights per Bushel of Commodities

III. Commodities for which bushel weights have been more widely adopted.

| | | Apples | | | Beans | | | | | | | | | | Coal | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Alfalfa Seed | Apples[1] | Dried Apples | Barley | Beans[1] | Castor Beans (Shelled) | Beets | Blue-grass Seed | Bran[1] | Broom-corn Seed | Buckwheat | Carrots | Charcoal | Clover Seed | Coal[1] | Bituminous Coal | Mineral Coal | Stone Coal |
| U. S. | | | | 48 | | 50 | | | | | 42 | | | | | 80 | | |
| Ala | | | 24 | 47 | 60 | | | | | | | | | | | | | |
| Ariz | | | | 45 | [2] 55 | | | | | | | | | | | | | |
| Ark | | [3] 50 | 24 | 48 | [2] 60 | | | 14 | 20 | 48 | 52 | | | 60 | | | | |
| Cal | | | | 50 | | | | | | | 40 | | | | | | | |
| Colo | | | | 48 | 60 | | | 14 | | | 52 | | | 60 | 80 | | 80 | |
| Conn | | 48 | 25 | 48 | 60 | | [4] 60 | | 20 | | 48 | 50 | 20 | 60 | | | | |
| Del | | | | | | | | | | | | | 20 | | | | | |
| D. C. | | | | | | | | | | | | | | | | | | |
| Fla | | [3] 48 | 24 | 48 | [5] 60 | 48 | | | 20 | | | | | | | | | |
| Ga | | | 24 | 47 | [6] 60 | | | 14 | [7] 20 | | 52 | | | 60 | | | | 80 |
| Hawaii | | | | 48 | | | | | | | | | | | | | | |
| Idaho[19] | | | | | | | | | | | | | | | | | | |
| Ill | | | 24 | 48 | [6] 60 | 46 | | 14 | 20 | | 52 | | | 60 | | | | 80 |
| Ind | | | 25 | 48 | 60 | 46 | | 14 | | | 50 | | | 60 | | | 80 | |
| Iowa | 60 | 48 | 24 | 48 | [8] 60 | 46 | 56 | 14 | 20 | 50 | 52 | 50 | 20 | 60 | | | | 80 |
| Kans | 60 | [3] 48 | 24 | 48 | 60 | 46 | 56 | [9] 14 | 20 | | 50 | 50 | | 60 | | | | 80 |
| Ky | | | 24 | 47 | [6] 60 | [1] 45 | | 14 | 20 | | 56 | | | 60 | 76 | 76 | 76 | 76 |
| La | | | | 48 | | | | | | | | | | | | | | |
| Me | | 44 | | 48 | 60 | | 60 | | | | 48 | 50 | | | | | | |

LEGAL WEIGHTS PER BUSHEL OF COMMODITIES

III. Commodities for which bushel weights have been more widely adopted.—*Cont.*

| | | Apples | | | Beans | | | | | | | | | | Coal | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Alfalfa Seed | Apples[1] | Dried Apples | Barley | Beans[1] | Castor Beans (Shelled) | Beets | Blue-grass Seed | Bran[1] | Broom-corn Seed | Buckwheat | Carrots | Charcoal | Clover Seed | Coal[1] | Bituminous Coal | Mineral Coal | Stone Coal |
| Md. | 60 | ... | 28 | 48 | 60 | [10] 50 | ... | 14 | 20 | ... | ... | 50 | 20 | 60 | 80 | ... | ... | ... |
| Mass. | ... | 48 | 25 | 48 | [11] 60 | ... | 60 | ... | 20 | ... | 48 | 50 | ... | 60 | ... | ... | ... | ... |
| Mich. | ... | 48 | 22 | 48 | 60 | 46 | ... | 14 | ... | ... | 48 | ... | ... | 60 | ... | ... | 80 | ... |
| Minn. | ... | [3] 50 | 28 | 48 | 60 | ... | 50 | 14 | ... | 57 | 50 | 45 | 20 | 60 | 80 | ... | ... | ... |
| Miss. | ... | ... | 26 | 48 | [6] 60 | [12] 46 | ... | 14 | 20 | ... | 48 | ... | ... | 60 | ... | ... | ... | 80 |
| Mo. | ... | 48 | 24 | 48 | [12] 60 | 46 | ... | 14 | 20 | ... | 52 | 50 | ... | 60 | ... | ... | 80 | ... |
| Mont. | ... | 45 | ... | 48 | 60 | ... | 50 | 14 | 20 | ... | 52 | 50 | ... | 60 | ... | ... | 76 | ... |
| Nebr. | 60 | [3] 48 | 24 | 48 | [6] 60 | 46 | ... | 14 | 20 | ... | 52 | ... | ... | 60 | ... | ... | ... | 80 |
| Nev. | 60 | [3] 48 | 24 | 48 | 60 | 46 | 56 | [9] | 20 | ... | 50 | 50 | ... | 60 | ... | ... | ... | ... |
| N. H. | ... | 48 | 25 | 48 | [2] [11] | ... | 60 | ... | 20 | ... | 48 | 50 | ... | 60 | ... | ... | ... | ... |
| N. J. | ... | 50 | 25 | 48 | 60 | ... | 60 | ... | ... | ... | 50 | 50 | ... | 64 | ... | ... | ... | ... |
| N. Mex. | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| N. Y. | ... | 48 | 25 | 48 | 60 | ... | ... | ... | 20 | ... | 48 | 50 | ... | 60 | ... | ... | ... | ... |
| N. C. | 60 | [3] 48 | ... | 48 | [13] 60 | [1] 46 | ... | 14 | ... | 46 | 50 | ... | ... | 60 | ... | ... | ... | ... |
| N. Dak. | ... | 50 | ... | 48 | 60 | ... | 60 | ... | 20 | 30 | 42 | ... | 60 | ... | ... | ... | ... | 80 |
| Ohio | ... | 50 | 24 | 48 | 60 | ... | 56 | ... | ... | ... | 50 | 50 | ... | 60 | ... | 80 | ... | ... |
| Okla. | 60 | 48 | 24 | 48 | 60 | 46 | 60 | 14 | 20 | 30 | 52 | 50 | ... | ... | 60 | ... | 80 | 80 |
| Oreg. | ... | 45 | 28 | 46 | ... | ... | ... | ... | ... | ... | 42 | ... | ... | 60 | ... | ... | ... | ... |
| Pa. | ... | ... | ... | 47 | ... | ... | ... | ... | ... | ... | 48 | ... | [14] [15] 18 | 60 | [16] 75 | 76 | ... | ... |
| R. I. | ... | 48 | 25 | 48 | 60 | 46 | 50 | ... | 20 | 48 | 50 | ... | 20 | 60 | 80 | ... | ... | ... |
| S. C. | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| S. Dak. | ... | ... | ... | 48 | 60 | ... | 60 | ... | 20 | 30 | 42 | ... | ... | 60 | ... | ... | ... | 80 |
| Tenn. | ... | [3] 50 | 24 | 48 | [12] [17] 60 | 46 | 50 | 14 | 20 | 42 | 50 | 50 | 22 | [18] 60 | ... | ... | ... | 80 |
| Tex. | ... | 45 | 28 | 48 | [6] 60 | ... | ... | ... | 20 | ... | 42 | ... | 22 | 60 | ... | ... | ... | 80 |
| Utah | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Vt. | ... | 46 | ... | 48 | 62 | ... | 60 | ... | ... | ... | 48 | 50 | ... | 60 | ... | ... | ... | ... |
| Va. | ... | ... | 28 | 48 | [6] 60 | ... | ... | 14 | ... | ... | 52 | ... | ... | 60 | ... | ... | ... | 80 |
| Wash. | ... | [3] 45 | 28 | 48 | ... | ... | ... | ... | ... | ... | 42 | ... | ... | 60 | ... | ... | ... | ... |
| W. Va. | ... | ... | 25 | 48 | 60 | ... | ... | ... | ... | ... | 52 | ... | ... | 60 | ... | 80 | ... | ... |
| Wis. | ... | 50 | 25 | 48 | 60 | ... | 50 | ... | 20 | ... | 50 | 50 | ... | 60 | ... | ... | ... | ... |
| Wyo. | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

[1] Not defined.
[2] Small white beans, 60 pounds.
[3] Green apples.
[4] Sugar beets and mangel-wurzel.
[5] Shelled beans, 60 pounds; velvet beans, 78 pounds.
[6] White beans.
[7] Wheat bran.
[8] Green unshelled beans, 56 pounds.
[9] English blue-grass seed, 22 pounds; native blue-grass seed, 14 pounds.
[10] Also castor seed.
[11] Soy beans, 58 pounds.
[12] Green unshelled beans, 30 pounds.
[13] Soy beans.
[14] Commercially dry, for all hard woods.
[15] Fifteen pounds commercially dry, for all soft woods.
[16] Standard weight in borough of Greensburg.
[17] Dried beans.
[18] Red and white.
[19] Idaho law repealed in 1905.

LEGAL WEIGHTS PER BUSHEL OF COMMODITIES

III. Commodities for which bushel weights have been more widely adopted.—*Cont.*

| | Coke | Corn[14] | | | | Corn Meal | | | Cotton Seed | | | Flaxseed (Linseed) | (Plastering) Hair | Hemp Seed | Herds Grass | Hungarian Grass Seed | Indian Corn or Maize |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Corn | Corn in Ear, Husked | Corn in Ear, Unhusked | Shelled Corn | Corn Meal[1] | Corn Meal, Bolted | Corn Meal, Unbolted | Cotton Seed[1] | Sea Island Cotton Seed | Upland Cotton Seed | | | | | | |
| U. S. | | 56 | | | | 48 | | | | | | 56 | | | | | |
| Ala. | | | 70 | 75 | 56 | | | | 32 | | | | | | | | |
| Ariz. | | 54 | | | | | | | | | | | | | | | |
| Ark. | | | 70 | 74 | 56 | 48 | | | 33⅓ | | | 56 | | | | | |
| Cal. | | | | | | | | | | | | | | | | | 52 |
| Colo. | | | 70 | | | 50 | | | | | | | | 44 | | | 56 |
| Conn. | | | | | | 50 | | | | 44 | 30 | 55 | | | 45 | | 56 |
| Del. | | | | | | | 44 | 48 | | | | | | | | | 56 |
| D. C. | | | | | | | | | | | | | | | | | |
| Fla. | | | | 70 | 56 | 48 | | | 32 | 46 | | | | | | | |
| Ga. | | | 70 | | 56 | 48 | | | 30 | | | 56 | 8 | 44 | | | |
| Hawaii | | | | | | | | | | | | | | | | | 56 |
| Idaho[15] | | | | | | | | | | | | | | | | | |
| Ill. | | | 70 | | 56 | 48 | | | | | | 56 | 8 | 44 | | | |
| Ind. | | | [2] | | 56 | 50 | | | | | | | | 44 | | | |
| Iowa | 38 | [3] 50 | [4] 70 | 75 | 56 | 50 | | | | | | 56 | | 44 | | 50 | |
| Kans. | | | [5] 70 | | 56 | | | | | | | 56 | [6] 8 | 44 | | 50 | |
| Ky. | | [7] 70 | | | 56 | 50 | | | | | | 56 | 8 | 44 | | 50 | |
| La. | | 56 | | | | | | | | | | | | | | | |
| Me. | | 56 | | | | [8] 50 | | | | | | | 11 | | 45 | | |
| Md. | | | [4] 70 | | 56 | 48 | | | | | | 56 | | 44 | 45 | 50 | |
| Mass. | | | | | [9] 50 | 50 | | | | 44 | 30 | 55 | | | 45 | | [10] 56 |
| Mich. | | | [4] 70 | | 56 | 50 | | | | | | 56 | | 44 | | 50 | |
| Minn. | | | 70 | | 56 | | | | | | | | [6] 8 | 50 | | 48 | |
| Miss. | | | 72 | | 56 | 48 | 44 | 48 | 32 | | | 56 | | 44 | | 50 | |
| Mo. | | | | 70 | 56 | 50 | | | 33 | | | 56 | | 44 | | 48 | |
| Mont. | | | 70 | | 56 | 50 | | | | | | 56 | | 44 | | 50 | |
| Nebr. | | | 70 | | 56 | 50 | | | | | | 56 | 8 | 44 | | 50 | |
| Nev. | | [5] 70 | | | 56 | 48 | | | | | | 56 | | 48 | | 50 | |
| N. H. | | [9] 50 | | | | 50 | | | | | | 56 | | | 45 | | 56 |
| N. J. | | | | | | | | | | | | 55 | | | | | 56 |
| N. Mex. | | | | | | | | | | | | | | | | | |
| N. Y. | | | | | | 50 | | | | 44 | 30 | 55 | | | 45 | | 56 |
| N. C. | | | 70 | | | 48 | | | 30 | 44 | | 55 | | 44 | | | 56 |
| N. Dak. | | | 70 | | 56 | | | | | | | 56 | | | | | |
| Ohio | 40 | | 68 | | 56 | | | | | | | 56 | | 44 | | 50 | |
| Okla. | | | 70 | 72 | 56 | 50 | | | 32 | | | 56 | | 44 | | | |
| Oreg. | | | | | | | | | | | | | | | | | 56 |
| Pa. | 40 | 58 | | | | | | | | | | | | | | | 56 |

LEGAL WEIGHTS PER BUSHEL OF COMMODITIES

III. Commodities for which bushel weights have been more widely adopted.—*Cont.*

| | Coke | Corn[14] | | | | Corn Meal[1] | | | Cotton Seed | | | Flaxseed (Linseed) | (Plastering) Hair | Hemp Seed | Herds Grass | Hungarian Grass Seed | Indian Corn or Maize |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Corn | Corn in Ear, Husked | Corn in Ear, Unhusked | Shelled Corn | Corn Meal[1] | Corn Meal Bolted | Corn Meal Unbolted | Cotton Seed[1] | Sea Island Cotton Seed | Upland Cotton Seed | | | | | | |
| R. I. | 40 | ... | 70 | ... | 56 | 50 | ... | ... | ... | 44 | 30 | 56 | ... | 44 | ... | 50 | ... |
| S. C. | ... | ... | ... | ... | ... | [11] 48 | 48 | 48 | [12] 30 | ... | ... | ... | ... | ... | ... | ... | ... |
| S. Dak. | ... | ... | 70 | ... | 56 | ... | ... | ... | ... | ... | ... | 56 | ... | ... | ... | ... | ... |
| Tenn. | 40 | ... | 70 | [13] 74 | 56 | ... | 50 | 48 | 28 | ... | ... | 56 | 8 | 44 | ... | 48 | ... |
| Tex. | ... | ... | 70 | 72 | 56 | ... | ... | ... | 32 | ... | ... | 56 | ... | 44 | ... | 48 | ... |
| Utah | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Vt. | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 45 | ... | 56 |
| Va. | ... | ... | 70 | ... | 56 | 50 | ... | ... | 32 | ... | ... | 56 | 8 | 44 | 12 | 48 | ... |
| Wash. | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 56 | ... | ... | ... | ... | 56 |
| W. Va. | ... | 56 | ... | ... | ... | ... | ... | ... | ... | ... | ... | 56 | ... | ... | ... | ... | ... |
| Wis. | ... | ... | ... | ... | ... | 50 | ... | ... | ... | 44 | 30 | 56 | 8 | 44 | ... | 48 | 56 |
| Wyo. | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

[1] Not defined.
[2] Corn in ear, 70 pounds until Dec. 1 next after grown; 68 pounds thereafter.
[3] Sweet corn.
[4] In the cob.
[5] Indian corn in ear.
[6] Unwashed plastering hair, 8 pounds: washed plastering hair, 4 pounds.
[7] Corn in ear, from Nov. 1 to May 1 following, 70 pounds, 68 pounds from May 1 to Nov. 1.
[8] Indian-corn meal.
[9] Cracked corn.
[10] Shelled.
[11] Standard weight bushel corn meal, bolted or unbolted, 48 pounds.
[12] Except the seed of long staple cotton, of which the weight shall be 42 pounds.
[13] Green unshelled corn, 100 pounds.
[14] See also "Popcorn," "Indian corn," and "Kaffir corn."
[15] Idaho law repealed in 1905.

## Legal Weights per Bushel of Commodities

III. Commodities for which bushel weights have been more widely adopted.—*Cont.*

| | Lime | | | | | | | | | Peaches | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lime[1] | Unslaked Lime | Malt | Millet | Oats | Onions[1] | Orchard Grass Seed | Osage Orange Seed | Parsnips | Peaches[1] | Dried Peaches, Peeled | Dried Peaches, Unpeeled | Peanuts (or "Ground Peas")* | Pears[1] | Peas[1] |
| U. S. | | | 34 | | 32 | | | | | | | | | | 60 |
| Ala. | | | | | 32 | | | | | | 38 | 33 | | | 60 |
| Ariz. | | | | | 32 | | | | | | | | | | |
| Ark. | | | | 50 | 32 | 57 | 14 | | | | 33 | 33 | | | 60 |
| Cal. | | | | | 32 | | | | | | | | | | |
| Colo. | 80 | | | | 32 | 57 | | | | | | | | | |
| Conn. | 70 | | | | 32 | 52 | | | 45 | | 33 | 33 | | | 60 |
| Del. | | | | | | | | | | | | | | | |
| D. C. | | | | | | | | | | | | | | | |
| Fla. | | | | 50 | 32 | 56 | | | | [2] 54 | 33 | | 22 | 60 | |
| Ga. | | 80 | | | 32 | 57 | | | | | 38 | 33 | *25 | | 60 |
| Hawaii | | | | | 32 | | | | | | | | | | |
| Idaho[29] | | | | | | | | | | | | | | | |
| Ill. | | 80 | 38 | | 32 | 57 | | | | | | 33 | | | |
| Ind. | | | [4] 35 | 50 | 32 | 48 | 14 | 33 | 55 | | | 33 | | | |
| Iowa | 80 | | | 50 | 32 | 57 | 14 | 32 | 42 | 48 | | 33 | 20 | | |
| Kans. | | 80 | 32 | 50 | 32 | 57 | | | 52 | 48 | | 33 | | | [7] 60 |
| Ky. | | 35 | | 50 | [8] 32 | 57 | 14 | | | | 39 | | *24 | | 60 |
| La. | | | | | | | | | | | | | | | |
| Me. | | | | | 32 | 52 | | | 45 | | | | | | 60 |
| Md. | 80 | | [4] 34 | [10] 50 | [11] 32 | 57 | 14 | | | [12] 40 | | | 22 | | [13] 60 |
| Mass. | 70 | | | | 32 | 52 | | | 45 | 48 | 33 | | [14] 20 | 58 | 60 |
| Mich. | 70 | | | 50 | 32 | 54 | 14 | 33 | | | 28 | | | | 60 |
| Minn. | 80 | | | 48 | 32 | 52 | 14 | | 42 | | [15] 28 | | | | 60 |
| Miss. | | 80 | 38 | 50 | 32 | 57 | | | | | 33 | | *24 | | 60 |
| Mo. | | | 38 | 50 | 32 | 57 | 14 | 36 | 44 | 48 | 33 | | | 48 | [17] 60 |
| Mont. | | 80 | 30 | | 32 | 57 | | | 50 | | | | | 45 | 60 |
| Nebr. | | 80 | 30 | 50 | 32 | 57 | | 32 | | | 33 | | | | 60 |
| Nev. | | | 32 | 50 | 32 | 57 | | | 50 | 48 | | [15] 33 | | | [7] 60 |
| N. H. | 70 | | | | 32 | 52 | | | 45 | 48 | | [15] 33 | [14] 20 | 58 | 60 |
| N. J. | | | | | 30 | 57 | | | | 50 | 33 | 33 | | | 60 |
| N. Mex. | | | | | | | | | | | | | | | 60 |
| N. Y. | 70 | | | | 32 | 57 | | | | | 33 | | | | |
| N. C. | | | | 50 | 32 | 57 | 14 | | | | | | 22 | | 60 |
| N. Dak. | 80 | | | 50 | 32 | 52 | | | | | | | | | 60 |
| Ohio | 70 | | 34 | 50 | 32 | 55 | | | | 48 | 33 | | | | 60 |
| Okla. | 80 | | 38 | 50 | 32 | 57 | 14 | 36 | 44 | 48 | | 33 | 22 | 48 | 60 |
| Oreg. | | | | | 32 | | | | | | 28 | | | 45 | |
| Pa. | | | | | 32 | 50 | | | | | | | | | |

LEGAL WEIGHTS PER BUSHEL OF COMMODITIES

III. Commodities for which bushel weights have been more widely adopted.—*Cont.*

| | Lime | | | | | | | | | Peaches | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lime[1] | Unslaked Lime | Malt | Millet | Oats | Onions[1] | Orchard Grass Seed | Osage Orange Seed | Parsnips | Peaches[1] | Dried Peaches, Peeled | Dried Peaches, Unpeeled | Peanuts (or "Ground Peas")* | Pears[1] | Peas[1] |
| R. I. | 70 | ... | 38 | 50 | 32 | 50 | ... | ... | 50 | 48 | 33 | .... | .... | .... | [3] 60 |
| S. C. | ... | ... | .... | .... | .... | .... | ... | ... | ... | .... | .... | .... | .... | .... | .... |
| S. Dak. | 80 | ... | .... | .... | 32 | 52 | ... | ... | ... | .... | .... | .... | .... | .... | 60 |
| Tenn. | [19] | 80 | .... | [20] 50 | 32 | [21] 56 | 14 | 33 | 50 | [23] 50 | 26 | .... | 23 | [24] 56 | 60 |
| Tex. | ... | ... | .... | 50 | 32 | 57 | ... | ... | ... | 50 | 28 | .... | .... | .... | .... |
| Utah | ... | ... | .... | .... | .... | .... | ... | ... | ... | .... | .... | .... | .... | .... | .... |
| Vt. | ... | ... | .... | .... | 32 | 52 | ... | ... | ... | .... | .... | .... | .... | .... | 60 |
| Va. | ... | 80 | 38 | 50 | 30 | 57 | 14 | 34 | ... | .... | 40 | 32 | 22 | .... | [25] 60 |
| Wash. | ... | ... | .... | .... | 32 | .... | ... | ... | ... | .... | 28 | .... | .... | [3] 45 | .... |
| W. Va. | ... | ... | .... | .... | 32 | .... | ... | ... | ... | .... | 33 | .... | .... | .... | .... |
| Wis. | 70 | 80 | [26] 34 | 50 | 32 | 57 | ... | ... | 44 | .... | 33 | .... | .... | .... | 60 |
| Wyo. | ... | ... | .... | .... | .... | .... | ... | ... | ... | .... | .... | .... | .... | .... | .... |

[1] Not defined.
[2] Green peaches.
[3] Green.
[4] Malt rye.
[5] Top sets; bottom sets 32 pounds.
[6] Shelled, 56 pounds.
[7] Shelled, dry.
[8] Strike measure.
[9] Bottom onion sets.
[10] German and American.
[11] Shelled.
[12] Peaches (peeled); unpeeled 32 pounds.
[13] Cowpeas.
[14] Roasted; green 22 pounds.
[15] Not stated whether peeled or unpeeled.
[16] Top onion sets.
[17] Including split peas.
[18] In the ear.
[19] Slaked lime, 40 pounds.
[20] German, Missouri, and Tennessee millet seeds.
[21] Matured onions.
[22] Bottom onion sets, 32 pounds.
[23] Matured.
[24] Matured pears, 56 pounds; dried pears, 26 pounds.
[25] Black-eyed pease.
[26] Barley malt.
[27] Includes "Rice corn."
[28] "Rive corn."
[29] Idaho law repealed in 1905.

LEGAL WEIGHTS PER BUSHEL OF COMMODITIES

III. Commodities for which bushel weights have been more widely adopted.—*Cont.*

| | Potatoes | | | | | | | | | | Salt | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Potatoes[1] | Sweet Potatoes | White Potatoes | Quinces | Rape Seed | Red Top | Rough Rice | Rutabagas | Rye Meal | Rye | Salt[1] | Fine Salt | Coarse Salt | Sorghum Seed | Timothy Seed | Tomatoes | Turnips[1] | Wheat |
| U. S. | 60 | ... | ... | ... | ... | ... | ... | ... | ... | 56 | ... | ... | ... | ... | ... | ... | ... | 60 |
| Ala. | ... | 55 | 60 | ... | ... | ... | ... | ... | ... | 56 | ... | ... | ... | ... | ... | ... | 55 | 60 |
| Ariz. | ... | ... | ... | ... | ... | ... | ... | ... | ... | 56 | ... | ... | ... | ... | ... | ... | ... | 60 |
| Ark. | 60 | 50 | ... | ... | ... | 14 | ... | ... | ... | 56 | 50 | ... | ... | 50 | 60 | ... | 57 | 60 |
| Cal. | ... | ... | ... | ... | ... | ... | ... | ... | ... | 54 | ... | ... | ... | ... | ... | ... | ... | 60 |
| Colo. | 60 | ... | ... | ... | ... | ... | ... | ... | ... | 56 | 80 | ... | ... | ... | 45 | ... | ... | 60 |
| Conn. | 60 | 54 | ... | ... | ... | ... | 45 | 60 | 50 | 56 | ... | 50 | 70 | ... | ... | ... | ... | 60 |
| Del. | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 60 |
| D. C. | 60 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Fla. | ... | 60 | 60 | 48 | ... | ... | ... | ... | ... | 56 | 60 | ... | ... | 56 | ... | ... | 54 | 60 |
| Ga. | ... | 55 | 60 | ... | ... | ... | 43 | ... | ... | 56 | ... | ... | ... | ... | 45 | ... | 55 | 60 |
| Hawaii | ... | ... | ... | ... | ... | ... | ... | ... | ... | 56 | ... | ... | ... | ... | ... | ... | ... | 60 |
| Idaho[8] | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Ill. | ... | 50 | 60 | ... | ... | ... | ... | ... | ... | 56 | ... | 55 | 50 | ... | 45 | ... | 55 | 60 |
| Ind. | 60 | 55 | ... | ... | ... | ... | ... | ... | ... | 56 | 50 | ... | ... | ... | 45 | ... | 55 | 60 |
| Iowa | 60 | 46 | ... | 48 | 50 | 14 | ... | 50 | ... | 56 | 80 | ... | ... | [2] 50 | 45 | 50 | 55 | 60 |
| Kans. | 60 | 50 | ... | ... | ... | ... | ... | ... | ... | 56 | 80 | ... | ... | 50 | 45 | 56 | 55 | 60 |
| Ky. | [5] 60 | 55 | ... | ... | ... | ... | ... | ... | ... | 56 | 50 | 55 | ... | ... | 45 | ... | 60 | 60 |
| La. | ... | ... | ... | ... | ... | ... | ... | ... | ... | 56 | ... | ... | ... | ... | ... | ... | ... | 60 |
| Me. | 60 | ... | ... | ... | ... | ... | ... | 60 | 50 | 50 | ... | 60 | 70 | ... | ... | ... | ... | 60 |
| Md. | 60 | 60 | ... | ... | 50 | [3] 14 | ... | ... | ... | 56 | ... | 56 | 70 | 50 | 45 | 60 | 60 | 60 |
| Mass. | 60 | 54 | ... | 48 | ... | ... | 45 | ... | 50 | 56 | ... | 50 | 70 | ... | 45 | 56 | 55 | 60 |
| Mich. | ... | 56 | 60 | ... | ... | [4] 14 | ... | ... | ... | 56 | 56 | ... | ... | ... | 45 | ... | 58 | 60 |
| Minn. | ... | 55 | 60 | ... | 50 | [4] 14 | ... | 52 | ... | 56 | ... | ... | ... | 57 | 45 | ... | ... | 60 |
| Miss. | ... | 60 | 60 | ... | ... | ... | ... | ... | ... | 56 | 50 | ... | ... | 42 | 45 | ... | 55 | 60 |
| Mo. | ... | 56 | 60 | ... | ... | [4] 14 | ... | 50 | ... | 56 | 50 | ... | ... | 42 | 45 | 45 | ... | 60 |
| Mont. | 60 | ... | ... | ... | ... | ... | ... | ... | ... | 56 | 50 | ... | ... | ... | 45 | ... | 50 | 60 |
| Nebr. | ... | 50 | 60 | ... | ... | ... | ... | ... | ... | 56 | 50 | ... | ... | 50 | 45 | ... | 55 | 60 |
| Nev. | 60 | 50 | ... | ... | ... | ... | ... | ... | ... | 56 | 80 | ... | ... | 50 | 45 | 56 | 56 | 60 |
| N. H. | [5] 60 | 54 | ... | 48 | ... | ... | ... | ... | 50 | 56 | ... | 50 | 70 | ... | 45 | 56 | 55 | 60 |
| N. J. | ... | 54 | 60 | ... | ... | ... | ... | ... | ... | 56 | ... | ... | ... | ... | 45 | ... | ... | 60 |
| N. Mex. | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| N. Y. | ... | 54 | 60 | ... | ... | ... | 45 | ... | 50 | 56 | ... | 56 | 70 | ... | 45 | ... | ... | 60 |
| N. C. | [5] 56 | 56 | 60 | ... | 50 | [4] 14 | 44 | ... | ... | 56 | ... | ... | ... | 50 | 45 | ... | 50 | 60 |
| N. Dak. | ... | 46 | 60 | ... | ... | ... | ... | ... | ... | 56 | 80 | ... | ... | ... | 45 | ... | 60 | 60 |
| Ohio | [5] 60 | 50 | ... | ... | ... | ... | ... | ... | ... | 56 | ... | ... | ... | ... | 45 | 56 | 60 | 60 |
| Okla. | ... | 55 | 60 | ... | 50 | [4] 14 | ... | 50 | ... | 56 | 80 | ... | ... | 50 | 45 | 45 | 60 | 60 |
| Oreg. | 60 | ... | ... | ... | ... | ... | ... | ... | ... | 56 | ... | ... | ... | ... | ... | ... | ... | 60 |
| Pa. | 56 | ... | ... | ... | ... | ... | ... | ... | ... | 56 | ... | [6] 62 | 85 | ... | ... | ... | ... | 60 |

LEGAL WEIGHTS PER BUSHEL OF COMMODITIES

III. Commodities for which bushel weights have been more widely adopted.—*Cont.*

| | Potatoes | | | | | | | | | | Salt | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Potatoes[1] | Sweet Potatoes | White Potatoes | Quinces | Rape Seed | Red Top | Rough Rice | Rutabagas | Rye Meal | Rye | Salt[1] | Fine Salt | Coarse Salt | Sorghum Seed | Timothy Seed | Tomatoes | Turnips[1] | Wheat |
| R. I. | ... | 54 | 60 | ... | ... | ... | ... | ... | 50 | 56 | ... | 50 | 70 | ... | 45 | 56 | 50 | 60 |
| S. C. | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| S. Dak. | ... | 46 | 60 | ... | ... | ... | ... | ... | ... | 56 | 80 | ... | ... | ... | 42 | ... | 60 | 60 |
| Tenn. | ... | 50 | 60 | 48 | ... | [4] 14 | ... | ... | ... | 56 | 50 | ... | ... | 50 | 45 | 56 | 50 | 60 |
| Tex. | ... | 55 | 60 | ... | ... | ... | ... | ... | ... | 56 | 50 | ... | ... | ... | 45 | 55 | 55 | 60 |
| Utah | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Vt. | 60 | ... | ... | ... | ... | ... | ... | ... | ... | 56 | 70 | ... | ... | ... | 45 | ... | 60 | [7] 60 |
| Va. | ... | 56 | 56 | ... | ... | 12 | ... | ... | ... | 56 | 50 | ... | ... | ... | 45 | ... | 55 | 60 |
| Wash. | 60 | ... | ... | ... | ... | ... | ... | ... | ... | 56 | ... | ... | ... | ... | ... | ... | ... | 60 |
| W. Va. | 60 | ... | ... | ... | ... | ... | ... | ... | ... | 56 | ... | ... | ... | ... | 45 | ... | ... | 60 |
| Wis. | 60 | 54 | ... | ... | 50 | ... | 45 | 56 | 50 | 56 | ... | 50 | 70 | ... | 45 | ... | 42 | 60 |
| Wyo. | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

[1] Not defined.
[2] Sorghum saccharatum seed.
[3] Red top grass seed (chaff); fancy 32 pounds.
[4] Seed.
[5] Irish potatoes.
[6] Ground salt, 70 pounds.
[7] India wheat, 46 pounds.
[8] Idaho law repealed in 1905.

## SECTION 3

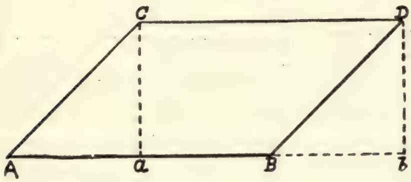
# MENSURATION AND MATHEMATICAL TABLES

## MENSURATION OF SURFACES

**To Find the Area of a Parallelogram**; whether it be a square, a rectangle, a rhombus, or a rhomboid.—Rule: Multiply the length by the height; or, multiply the product of two contiguous sides by the natural sine of the included angle.

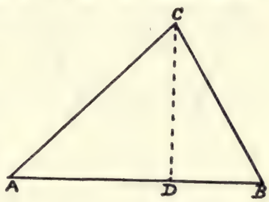
NOTE.—The perpendicular height of the parallelogram is equal to the area divided by the base.

The area of a parallelogram which is not right angled can be converted into a rectangle by cutting off a triangle at one end and putting it on the other.




Its area is the length multiplied into the breadth measured perpendicularly, or, as it is commonly stated,—Area = base × altitude.

**To Find the Area of a Triangle.**—Rule: Multiply the base by the perpendicular height and take half the product. Or, multiply half the product of two contiguous sides by the natural sine of the included angle.

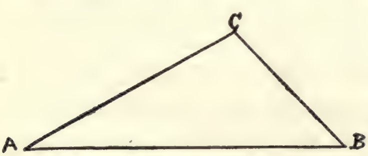



NOTE.—A triangle is half a parallelogram of the same base and altitude.

The perpendicular height of the triangle is equal to twice the area divided by the base.

**To Find the Area of a Triangle Whose Three Sides Only Are Given.**—Rule 1. From half the sum of the three sides subtract each side severally.

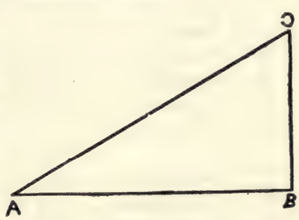
Multiply half the sum and the three remainders continually together, and the square root of the product will be the area required.




Rule 2. Any two sides of a triangle being multiplied together and the product again by half the natural sine of their included angle will give the area of the triangle.

That is, AC multiplied by CB × natural sine of the angle C = twice area.

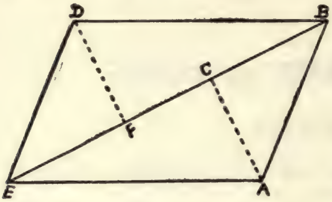
**Any Two Sides of a Right Angle Triangle Being Given to Find the Third Side.**—Rule 1. When the two legs are given to find the hypotenuse. Add the square of one of the legs to the square of the other, and the square root of the sum will be equal to the hypotenuse.




Rule 2. When the hypotenuse and one of the legs are given to find the other leg. From the square of the hypotenuse take the square of the given leg, and the square root of the remainder will be equal to the other leg.

**To Find the Area of a Trapezium.**—Rule: Multiply the diagonal by the sum of the two perpendiculars falling upon it from the opposite angles, and half the product will be the area.

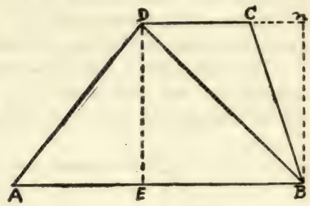
NOTE.—If the trapezium can be inscribed in a circle; that is, if the sum of two of its opposite angles is equal to two right angles, or 180°, the area may be found thus:




Rule: From half the sum of the four sides subtract each side severally; then multiply the four remainders continually together, and the square root of the product will be the area.

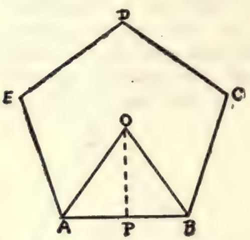
**To Find the Area of a Trapezoid, or a Quadrangle, Two of Whose Opposite Sides Are Parallel.**—Rule: Multiply the sum of the parallel sides by the perpendicular distance between them, and half the product will be the area.

**To Find the Area of a Regular Polygon.**—Rule: Multiply half the perimeter of the figure by the perpendicular falling from its center upon one of the sides, and the product will be the area.




NOTE.—Every regular polygon is composed of as many equal triangles as it has sides, consequently the area of one of those triangles being multiplied by the number of sides must give the area of the whole figure.

**To Find the Area of a Regular Polygon When the Side Only Is Given.**—Rule: Multiply the square of the side of the polygon by the number standing opposite its name in the following table and the product will be the area.




NOTE.—The multipliers in the table are the areas of the polygon to which they belong when the side is unity or one. The table is formed by trigonometry, thus:

$$\text{As radius} = 1 : \text{tang.} \angle OBP : : BP\ (\tfrac{1}{2}) : PO =$$

$$\frac{BP \times \text{tang.} \angle OPB}{\text{radius}} = \tfrac{1}{2}\,\text{tang.} \angle OBP :$$

Whence $OP \times BP = \frac{1}{4}$ tang. $\angle OBP$ = area of the $\Delta AOB$; and $\frac{1}{4}$ tang. $\angle OBP \times$ number of sides = tabular number, or the area of the polygon.

The angle O B P, together with its tangent, for any polygon of not more than twelve sides is shown in the following table:

| No. of Sides | Names | Multipliers | Angle OBP | Tangents |
|---|---|---|---|---|
| 3 | Trigon or equil. Δ ..... | 0.433013− | 30° | .57735+ $= \frac{1}{3}\sqrt{3}$ |
| 4 | Tetragon or square..... | 1.000000+ | 45° | 1.00000+ $= 1 \times 1$ |
| 5 | Pentagon............. | 1.720477+ | 54° | 1.37638+ $= \sqrt{1+\frac{2}{5}\sqrt{5}}$ |
| 6 | Hexagon.............. | 2.598076+ | 60° | 1.73205+ $= \sqrt{3}$ |
| 7 | Heptagon............. | 3.633912+ | 64° | 2.07652+ |
| 8 | Octagon.............. | 4.828427+ | 67°$\frac{2}{7}$ | 2.41421+ $= 1+\sqrt{2}$ |
| 9 | Nonagon.............. | 6.181824+ | 70°$\frac{1}{2}$ | 2.74747+ |
| 10 | Decagon.............. | 7.694209− | 72° | 3.07768+ $= \sqrt{5+2\sqrt{5}}$ |
| 11 | Undecagon............ | 9.365640− | 73°$\frac{7}{11}$ | 3.40568+ |
| 12 | Duodecagon........... | 11.196152+ | 75° | 3.73205+ $= 2+\sqrt{3}$ |

**To Find the Area of Any Polygon.**—Rule: Divide the polygon into triangles and trapezoids by drawing diagonals· find the area of these as above shown, fo: the area.

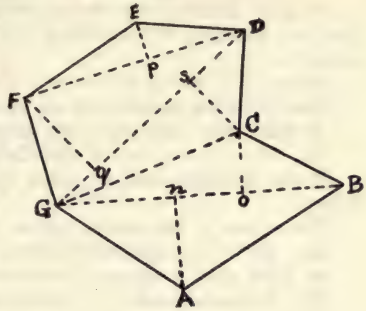
**To Find the Area of Any Quadrilateral Figure.**—Rule: Divide the quadrilateral into two triangles; the sum of the areas of the triangles is the area.

Or, multiply half the product of the two diagonals by the natural sine of the angle of their intersection.

NOTE.—As the diagonal of a square and a rhombus intersect at right angles (the natural sine of which is 1), half the product of their diagonals is the area.

**To Find the Area of an Irregular Polygon or Figure of Any Number of Sides.**—Rule: Divide the figure into triangles and trapeziums, and find the area of each separately.

Add these areas together and the sum will be the area of the whole polygon.




## CIRCLES

The proportion of the diameter of a circle to its circumference has never yet been exactly ascertained. Nor can a square or any other right lined figure be found that shall be equal to a given circle.

Though the relation between the diameter and circumference cannot be accurately expressed in known numbers, it may yet be approximated to any assigned degree of exactness. Van Ceulen, a Dutchman, in his book, "*De Circulo et Adscriptis,*" showed that if the diameter of a circle was 1, the circumference would be 3.141592653589793 and so on to thirty-six places of decimals. This is commonly abbreviated as 1 to 3.1416.

When the diameter = 1, the area is equal to .785398+, commonly abbreviated to .7854.

In these ratios, the diameter and circumference are taken lineally and the area superficially. If the diameter is in inches, the circumference will be in lineal inches, the area in square inches.

The circumference of a circle is commonly signified by the Greek letter $\pi$, which indicates the length of the circumference when the diameter is 1.

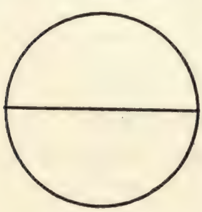
D = diameter of circle, $\pi$ = circumference of circle, A = area of circle,

$$A = \frac{\pi}{4} D^2 = .7854\, D^2. \quad D = \frac{2\sqrt{A}}{\sqrt{\pi}} = 1.1284\sqrt{A}.$$

If the diameter be multiplied or divided by any number, the area must be multiplied or divided by the square of that number. Thus:

$$\text{Diameter} = nD. \quad \text{Area} = n^2A. \quad \text{Diameter} = \frac{D}{n}. \quad \text{Area} = \frac{A}{n^2}.$$

**The Diameter of a Circle Being Given to Find the Circumference**; or, the circumference being given to find the diameter.—Rule: Multiply the diameter by 3.1416, and the product will be the circumference, or, divide the circumference by 3.1416, and the quotient will be the diameter.



NOTE.—1. As 7 is to 22, so is the diameter to the circumference; or, as 22 is to 7, so is the circumference to the diameter.

2. As 113 is to 355, so is the diameter to the circumference; or, as 355 is to 113, so is the circumference to the diameter.

**To Find the Area of a Circle.**—Rule 1. Multiply half the circumference by half the diameter, and the product will be the area.

Or, take one-fourth the product of the whole circumference and diameter.

NOTE.—A circle may be considered as a regular polygon of an infinite number of sides, the circumference being equal to the perimeter, and the radius to the perpendicular. But the area of a regular polygon is equal to half the

perimeter multiplied by the perpendicular, and consequently the area of a circle is equal to half the circumference multiplied by the radius, or half the diameter.

Rule 2. Multiply the square of the diameter by .7854, and the product will be the area; or, multiply the square of the circumference by .07958, and the product will be the area.

NOTE.—All circles are to each other as the squares of their diameters.

The following proportions are those of Metius and Archimedes:

As 452 : 355 :: square of the diameter : area.

As 14 : 11 :: square of the diameter : area.

If the circumference be given instead of the diameter, the area may be found as follows:

The square of the circumference × .07958 = area.

As 88 : 7 :: square of the circumference : area.

As 1420 : 113 :: square of the circumference : area.

The following table will show most of the useful problems relating to the circle and its equal or inscribed square:

| | | |
|---|---|---|
| Diameter × | .8862 | = side of an equal square. |
| Circumference × | .2821 | = side of an equal square. |
| Diameter × | .7071 | = side of an inscribed square. |
| Circumference × | .2251 | = side of the inscribed square. |
| Area × | .6366 | = side of the inscribed square. |
| Side of a square × | 1.4142 | = diameter of its circumscribing circle. |
| Side of a square × | 4.443 | = circumference of its circumscribing circle. |
| Side of a square × | 1.128 | = diameter of an equal circle. |
| Side of a square × | 3.545 | = circumference of an equal circle. |
| Radius × | 6.2832 | = circumference. |
| Circumference × | .3183 | = diameter. |
| Circumference | | $= 3.5449\ \sqrt{\text{area of a circle}}$. |
| Diameter | | $= 1.1283\ \sqrt{\text{area of a circle}}$. |
| Length of arc | | = number of degrees × .0175 radius. |
| | | arc of 1° to radius 1 = 0.017453. |
| | | arc of 1′ to radius 1 = 0.000291. |
| | | arc of 1″ to radius 1 = 0.00000485. |

Degrees in arc whose length = radius = 57° .2958.

## Useful Functions of $\pi$

$\pi$ = ratio of circumference to diameter
$\pi = 3.1415926536$

| | N | 2 N | 3 N | 4 N | 5 N | 6 N | 7 N | 8 N | 9 N |
|---|---|---|---|---|---|---|---|---|---|
| $\pi =$ | 3.1416 | 6.2832 | 9.4248 | 12.5664 | 15.7080 | 18.8496 | 21.9911 | 25.1327 | 28.2743 |
| $\frac{\pi}{2} =$ | 1.5708 | 3.1416 | 4.7124 | 6.2832 | 7.8540 | 9.4248 | 10.9956 | 12.5664 | 14.1372 |
| $\frac{\pi}{3} =$ | 1.0472 | 2.0944 | 3.1416 | 4.1888 | 5.2360 | 6.2832 | 7.3304 | 8.3776 | 9.4248 |
| $\frac{\pi}{4} =$ | .7854 | 1.5708 | 2.3562 | 3.1416 | 3.9270 | 4.7124 | 5.4978 | 6.2832 | 7.0686 |
| $\frac{\pi}{6} =$ | .5236 | 1.0472 | 1.5708 | 2.0944 | 2.6180 | 3.1416 | 3.6652 | 4.1888 | 4.7124 |
| $\frac{\pi}{7} =$ | .4488 | .8976 | 1.3464 | 1.7952 | 2.2440 | 2.6928 | 3.1416 | 3.5904 | 4.0392 |
| $\frac{\pi}{16} =$ | .1963 | .3927 | .5890 | .7854 | .9817 | 1.1781 | 1.3744 | 1.5708 | 1.7671 |
| $\frac{\pi}{24} =$ | .1309 | .2618 | .3927 | .5236 | .6545 | .7854 | .9163 | 1.0472 | 1.1781 |
| $\frac{\pi}{32} =$ | .0982 | .1964 | .2945 | .3927 | .4909 | .5890 | .6872 | .7854 | .8836 |
| $\frac{\pi}{180} =$ | .0175 | .0349 | .0524 | .0698 | .0873 | .1047 | .1222 | 1396 | .1571 |
| $\pi^2 =$ | 9.8696 | 19.7392 | 29.6088 | 39.4784 | 49.3480 | 59.2176 | 69.0872 | 78.9568 | 88.8264 |
| $\pi^3 =$ | 31.0063 | 62.0126 | 93.0188 | 124.0251 | 155.0314 | 186.0377 | 217.0439 | 248.0502 | 279.0565 |
| $\frac{1}{\pi} =$ | .3183 | .6366 | .9549 | 1.2732 | 1.5915 | 1.9099 | 2.2282 | 2.5465 | 2.8648 |
| $\frac{1}{\pi^2} =$ | .1013 | .2026 | .3040 | .4053 | .5066 | .6079 | .7092 | .8106 | .9119 |
| $\frac{1}{\pi^3} =$ | .0323 | .0645 | .0968 | .1290 | .1613 | .1935 | .2258 | .2580 | .2903 |
| $\sqrt{\pi} =$ | 1.7725 | 3.5449 | 5.3174 | 7.0898 | 8.8623 | 10.6347 | 12.4072 | 14.1796 | 15.9521 |
| $\sqrt[3]{\pi} =$ | 1.4646 | 2.9292 | 4.3938 | 5.8584 | 7.3230 | 8.7876 | 10.2521 | 11.7167 | 13.1813 |
| $\sqrt{\frac{1}{\pi}} =$ | .5642 | 1.1284 | 1.6926 | 2.2568 | 2.8209 | 3.3851 | 3.9493 | 4.5135 | 5.0777 |
| $\frac{1}{\sqrt[3]{\pi}} =$ | .6828 | 1.3656 | 2.0484 | 2.7311 | 3.4139 | 4.0967 | 4.7795 | 5.4623 | 6.1451 |
| Log $\pi =$ | .4971499 | .9943 | 1.4915 | 1.9886 | 2.4857 | 2.9829 | 3.4800 | 3.9772 | 4.4743 |

CIRCLES—DIAMETER, CIRCUMFERENCE, AREA, AND SIDE OF EQUAL SQUARE FROM 1 TO 120

| Diameter | Circumference | Area | Side of Equal Square (Square Root of Area) | Diameter | Circumference | Area | Side of Equal Square (Square Root of Area) |
|---|---|---|---|---|---|---|---|
| | | | | 3 | 9.4248 | 7.0686 | 2.6586 |
| 1/16 | .1963 | .00307 | .0553 | 3 1/16 | 9.6211 | 7.3662 | 2.7140 |
| 1/8 | .3927 | .01227 | .1107 | 3 1/8 | 9.8175 | 7.6699 | 2.7694 |
| 3/16 | .5890 | .02761 | .1661 | 3 3/16 | 10.014 | 7.9798 | 2.8248 |
| 1/4 | .7854 | .04909 | .2215 | 3 1/4 | 10.210 | 8.2957 | 2.8801 |
| 5/16 | .9817 | .07670 | .2770 | 3 5/16 | 10.406 | 8.6180 | 2.9355 |
| 3/8 | 1.1781 | .1104 | .3323 | 3 3/8 | 10.602 | 8.9462 | 2.9909 |
| 7/16 | 1.3744 | .1503 | .3877 | 3 7/16 | 10.799 | 9.2807 | 3.0463 |
| 1/2 | 1.5708 | .1963 | .4431 | 3 1/2 | 10.995 | 9.6211 | 3.1017 |
| 9/16 | 1.7771 | .2485 | .4984 | 3 9/16 | 11.191 | 9.9680 | 3.1571 |
| 5/8 | 1.9635 | .3068 | .5539 | 3 5/8 | 11.388 | 10.320 | 3.2124 |
| 11/16 | 2.1598 | .3712 | .6092 | 3 11/16 | 11.584 | 10.679 | 3.2678 |
| 3/4 | 2.3562 | .4417 | .6646 | 3 3/4 | 11.781 | 11.044 | 3.3232 |
| 13/16 | 2.5525 | .5185 | .7200 | 3 13/16 | 11.977 | 11.416 | 3.3786 |
| 7/8 | 2.7489 | .6013 | .7754 | 3 7/8 | 12.173 | 11.793 | 3.4340 |
| 15/16 | 2.9452 | .6903 | .8308 | 3 15/16 | 12.369 | 12.177 | 3.4894 |
| 1 | 3.1416 | .7854 | .8862 | 4 | 12.566 | 12.566 | 3.5448 |
| 1 1/16 | 3.3379 | .8866 | .9416 | 4 1/16 | 12.762 | 12.962 | 3.6002 |
| 1 1/8 | 3.5343 | .9940 | .9969 | 4 1/8 | 12.959 | 13.364 | 3.6555 |
| 1 3/16 | 3.7306 | 1.1075 | 1.0524 | 4 3/16 | 13.155 | 13.772 | 3.7109 |
| 1 1/4 | 3.9270 | 1.2271 | 1.1017 | 4 1/4 | 13.351 | 14.186 | 3.7663 |
| 1 5/16 | 4.1233 | 1.3530 | 1.1631 | 4 5/16 | 13.547 | 14.606 | 3.8217 |
| 1 3/8 | 4.3197 | 1.4848 | 1.2185 | 4 3/8 | 13.744 | 15.033 | 3.8771 |
| 1 7/16 | 4.5160 | 1.6229 | 1.2739 | 4 7/16 | 13.940 | 15.465 | 3.9325 |
| 1 1/2 | 4.7124 | 1.7671 | 1.3293 | 4 1/2 | 14.137 | 15.904 | 3.9880 |
| 1 9/16 | 4.9087 | 1.9175 | 1.3847 | 4 9/16 | 14.333 | 16.349 | 4.0434 |
| 1 5/8 | 5.1051 | 2.0739 | 1.4401 | 4 5/8 | 14.529 | 16.800 | 4.0987 |
| 1 11/16 | 5.3014 | 2.2365 | 1.4955 | 4 11/16 | 14.725 | 17.257 | 4.1541 |
| 1 3/4 | 5.4978 | 2.4052 | 1.5508 | 4 3/4 | 14.922 | 17.720 | 4.2095 |
| 1 13/16 | 5.6941 | 2.5800 | 1.6062 | 4 13/16 | 15.119 | 18.190 | 4.2648 |
| 1 7/8 | 5.8905 | 2.7611 | 1.6616 | 4 7/8 | 15.315 | 18.665 | 4.3202 |
| 1 15/16 | 6.0868 | 2.9483 | 1.7170 | 4 15/16 | 15.511 | 19.147 | 4.3756 |
| 2 | 6.2832 | 3.1416 | 1.7724 | 5 | 15.708 | 19.635 | 4.4310 |
| 2 1/16 | 6.4795 | 3.3380 | 1.8278 | 5 1/16 | 15.904 | 20.129 | 4.4864 |
| 2 1/8 | 6.6759 | 3.5465 | 1.8831 | 5 1/8 | 16.100 | 20.629 | 4.5417 |
| 2 3/16 | 6.8722 | 3.7584 | 1.9385 | 5 3/16 | 16.296 | 21.135 | 4.5971 |
| 2 1/4 | 7.0686 | 3.9760 | 1.9939 | 5 1/4 | 16.493 | 21.647 | 4.6525 |
| 2 5/16 | 7.2649 | 4.2000 | 2.0493 | 5 5/16 | 16.689 | 22.166 | 4.7079 |
| 2 3/8 | 7.4613 | 4.4302 | 2.1047 | 5 3/8 | 16.886 | 22.690 | 4.7633 |
| 2 7/16 | 7.6576 | 4.6664 | 2.1601 | 5 7/16 | 17.082 | 23.221 | 4.8187 |
| 2 1/2 | 7.8540 | 4.9087 | 2.2155 | 5 1/2 | 17.278 | 23.758 | 4.8741 |
| 2 9/16 | 8.0503 | 5.1573 | 2.2709 | 5 9/16 | 17.474 | 24.301 | 4.9295 |
| 2 5/8 | 8.2467 | 5.4119 | 2.3262 | 5 5/8 | 17.671 | 24.850 | 4.9848 |
| 2 11/16 | 8.4430 | 5.6723 | 2.3816 | 5 11/16 | 17.867 | 25.406 | 5.0402 |
| 2 3/4 | 8.6394 | 5.9395 | 2.4370 | 5 3/4 | 18.064 | 25.967 | 5.0956 |
| 2 13/16 | 8.8357 | 6.2126 | 2.4924 | 5 13/16 | 18.231 | 26.535 | 5.1510 |
| 2 7/8 | 9.0321 | 6.4918 | 2.5478 | 5 7/8 | 18.457 | 27.108 | 5.2064 |
| 2 15/16 | 9.2284 | 6.7772 | 2.6032 | 5 15/16 | 18.653 | 27.688 | 5.2618 |

CIRCLES—DIAMETER, CIRCUMFERENCE, AREA, ETC.—(*Cont.*)

| Diameter | Circumference | Area | Side of Equal Square (Square Root of Area) | Diameter | Circumference | Area | Side of Equal Square (Square Root of Area) |
|---|---|---|---|---|---|---|---|
| 6 | 18.849 | 28.274 | 5.3172 | 11½ | 36.128 | 103.869 | 10.191 |
| 6⅛ | 19.242 | 29.464 | 5.4280 | 11⅝ | 36.521 | 106.139 | 10.302 |
| 6¼ | 19.635 | 30.679 | 5.5388 | 11¾ | 36.913 | 108.434 | 10.413 |
| 6⅜ | 20.027 | 31.919 | 5.6495 | 11⅞ | 37.306 | 110.753 | 10.523 |
| 6½ | 20.420 | 33.183 | 5.7603 | | | | |
| 6⅝ | 20.813 | 34.471 | 5.8711 | 12 | 37.699 | 113.097 | 10.634 |
| 6¾ | 21.205 | 35.784 | 5.9819 | 12⅛ | 38.091 | 115.466 | 10.745 |
| 6⅞ | 21.598 | 37.122 | 6.0927 | 12¼ | 38.484 | 117.859 | 10.856 |
| | | | | 12⅜ | 38.877 | 120.276 | 10.966 |
| 7 | 21.991 | 38.484 | 6.2034 | 12½ | 39.270 | 122.718 | 11.077 |
| 7⅛ | 22.383 | 39.871 | 6.3142 | 12⅝ | 39.662 | 125.184 | 11.188 |
| 7¼ | 22.776 | 41.282 | 6.4350 | 12¾ | 40.055 | 127.676 | 11.299 |
| 7⅜ | 23.169 | 42.718 | 6.5358 | 12⅞ | 40.448 | 130.192 | 11.409 |
| 7½ | 23.562 | 44.178 | 6.6465 | | | | |
| 7⅝ | 23.954 | 45.663 | 6.7573 | 13 | 40.840 | 132.732 | 11.520 |
| 7¾ | 24.347 | 47.173 | 6.8681 | 13⅛ | 41.233 | 135.297 | 11.631 |
| 7⅞ | 24.740 | 48.707 | 6.9789 | 13¼ | 41.626 | 137.886 | 11.742 |
| | | | | 13⅜ | 42.018 | 140.500 | 11.853 |
| 8 | 25.132 | 50.265 | 7.0897 | 13½ | 42.411 | 143.139 | 11.963 |
| 8⅛ | 25.515 | 51.848 | 7.2005 | 13⅝ | 42.804 | 145.802 | 12.074 |
| 8¼ | 25.918 | 53.456 | 7.3112 | 13¾ | 43.197 | 148.489 | 12.185 |
| 8⅜ | 26.310 | 55.088 | 7.4220 | 13⅞ | 43.589 | 151.201 | 12.296 |
| 8½ | 26.703 | 56.745 | 7.5328 | | | | |
| 8⅝ | 27.096 | 58.426 | 7.6436 | 14 | 43.982 | 153.938 | 12.406 |
| 8¾ | 27.489 | 60.132 | 7.7544 | 14⅛ | 44.375 | 156.699 | 12.517 |
| 8⅞ | 27.881 | 61.862 | 7.8651 | 14¼ | 44.767 | 159.485 | 12.628 |
| | | | | 14⅜ | 45.160 | 162.295 | 12.739 |
| 9 | 28.274 | 63.617 | 7.9760 | 14½ | 45.553 | 165.130 | 12.850 |
| 9⅛ | 28.667 | 65.396 | 8.0866 | 14⅝ | 45.945 | 167.989 | 12.960 |
| 9¼ | 29.059 | 67.200 | 8.1974 | 14¾ | 46.338 | 170.873 | 13.071 |
| 9⅜ | 29.452 | 69.029 | 8.3081 | 14⅞ | 46.731 | 173.872 | 13.182 |
| 9½ | 29.845 | 70.882 | 8.4190 | | | | |
| 9⅝ | 30.237 | 72.759 | 8.5297 | 15 | 47.124 | 176.715 | 13.293 |
| 9¾ | 30.630 | 74.662 | 8.6405 | 15⅛ | 47.516 | 179.672 | 13.403 |
| 9⅞ | 31.023 | 76.588 | 8.7513 | 15¼ | 47.909 | 182.654 | 13.514 |
| | | | | 15⅜ | 48.302 | 185.661 | 13.625 |
| 10 | 31.416 | 78.540 | 8.8620 | 15½ | 48.694 | 188.692 | 13.736 |
| 10⅛ | 31.808 | 80.515 | 8.9728 | 15⅝ | 49.087 | 191.748 | 13.847 |
| 10¼ | 32.201 | 82.516 | 9.0836 | 15¾ | 49.480 | 194.828 | 13.957 |
| 10⅜ | 32.594 | 84.540 | 9.1943 | 15⅞ | 49.872 | 197.933 | 14.068 |
| 10½ | 32.986 | 86.590 | 9.3051 | | | | |
| 10⅝ | 33.379 | 88.664 | 9.4159 | 16 | 50.265 | 201.062 | 14.179 |
| 10¾ | 33.772 | 90.762 | 9.5267 | 16⅛ | 50.658 | 204.216 | 14.290 |
| 10⅞ | 34.164 | 92.885 | 9.6375 | 16¼ | 51.051 | 207.394 | 14.400 |
| | | | | 16⅜ | 51.443 | 210.597 | 14.511 |
| 11 | 34.557 | 95.033 | 9.7482 | 16½ | 51.836 | 213.825 | 14.622 |
| 11⅛ | 34.950 | 97.205 | 9.8590 | 16⅝ | 52.229 | 217.077 | 14.732 |
| 11¼ | 35.343 | 99.402 | 9.9698 | 16¾ | 52.621 | 220.353 | 14.843 |
| 11⅜ | 35.735 | 101.623 | 10.080 | 16⅞ | 53.014 | 223.654 | 14.954 |

CIRCLES—DIAMETER, CIRCUMFERENCE, AREA, ETC.—(*Cont.*)

| Diameter | Circumference | Area | Side of Equal Square (Square Root of Area) | Diameter | Circumference | Area | Side of Equal Square (Square Root of Area) |
|---|---|---|---|---|---|---|---|
| 17 | 53.407 | 226.980 | 15.065 | 22½ | 70.686 | 397.608 | 19.939 |
| 17⅛ | 53.799 | 230.330 | 15.176 | 22⅝ | 71.078 | 402.038 | 20.050 |
| 17¼ | 54.192 | 233.705 | 15.286 | 22¾ | 71.471 | 406.493 | 20.161 |
| 17⅜ | 54.585 | 237.104 | 15.397 | 22⅞ | 71.864 | 410.972 | 20.271 |
| 17½ | 54.978 | 240.528 | 15.508 | | | | |
| 17⅝ | 55.370 | 243.977 | 15.619 | 23 | 72.256 | 415.476 | 20.382 |
| 17¾ | 55.763 | 247.450 | 15.730 | 23⅛ | 72.649 | 420.004 | 20.493 |
| 17⅞ | 56.156 | 250.947 | 15.840 | 23¼ | 73.042 | 424.557 | 20.604 |
| | | | | 23⅜ | 73.434 | 429.135 | 20.715 |
| 18 | 56.548 | 254.469 | 15.951 | 23½ | 73.827 | 433.731 | 20.825 |
| 18⅛ | 56.941 | 258.016 | 16.062 | 23⅝ | 74.220 | 438.363 | 20.936 |
| 18¼ | 57.334 | 261.587 | 16.173 | 23¾ | 74.613 | 443.014 | 21.047 |
| 18⅜ | 57.726 | 265.182 | 16.283 | 23⅞ | 75.005 | 447.699 | 21.158 |
| 18½ | 58.119 | 268.803 | 16.394 | | | | |
| 18⅝ | 58.512 | 272.447 | 16.505 | 24 | 75.398 | 452.390 | 21.268 |
| 18¾ | 58.905 | 276.117 | 16.616 | 24⅛ | 75.791 | 457.115 | 21.379 |
| 18⅞ | 59.297 | 279.811 | 16.727 | 24¼ | 76.183 | 461.864 | 21.490 |
| | | | | 24⅜ | 76.576 | 466.638 | 21.601 |
| 19 | 59.690 | 283.529 | 16.837 | 24½ | 76.969 | 471.436 | 21.712 |
| 19⅛ | 60.083 | 287.272 | 16.948 | 24⅝ | 77.361 | 476.259 | 21.822 |
| 19¼ | 60.475 | 291.039 | 17.060 | 24¾ | 77.754 | 481.106 | 21.933 |
| 19⅜ | 60.868 | 294.831 | 17.170 | 24⅞ | 78.147 | 485.978 | 22.044 |
| 19½ | 61.261 | 298.648 | 17.280 | | | | |
| 19⅝ | 61.653 | 302.489 | 17.391 | 25 | 78.540 | 490.875 | 22.155 |
| 19¾ | 62.046 | 306.355 | 17.502 | 25⅛ | 78.932 | 495.796 | 22.265 |
| 19⅞ | 62.439 | 310.245 | 17.613 | 25¼ | 79.325 | 500.741 | 22.376 |
| | | | | 25⅜ | 79.718 | 505.711 | 22.487 |
| 20 | 62.832 | 314.160 | 17.724 | 25½ | 80.110 | 510.706 | 22.598 |
| 20⅛ | 63.224 | 318.099 | 17.834 | 25⅝ | 80.503 | 515.725 | 22.709 |
| 20¼ | 63.617 | 322.063 | 17.945 | 25¾ | 80.896 | 520.769 | 22.819 |
| 20⅜ | 64.010 | 326.051 | 18.056 | 25⅞ | 81.288 | 525.837 | 22.930 |
| 20½ | 64.402 | 330.064 | 18.167 | | | | |
| 20⅝ | 64.795 | 334.101 | 18.277 | 26 | 81.681 | 530.930 | 23.041 |
| 20¾ | 65.188 | 338.163 | 18.388 | 26⅛ | 82.074 | 536.047 | 23.152 |
| 20⅞ | 65.580 | 342.250 | 18.499 | 26¼ | 82.467 | 541.189 | 23.262 |
| | | | | 26⅜ | 82.859 | 546.356 | 23.373 |
| 21 | 65.973 | 346.361 | 18.610 | 26½ | 83.252 | 551.547 | 23.484 |
| 21⅛ | 66.366 | 350.497 | 18.721 | 26⅝ | 83.645 | 556.762 | 23.595 |
| 21¼ | 66.759 | 354.657 | 18.831 | 26¾ | 84.037 | 562.002 | 23.708 |
| 21⅜ | 67.151 | 358.841 | 18.942 | 26⅞ | 84.430 | 567.267 | 23.816 |
| 21½ | 67.544 | 363.051 | 19.053 | | | | |
| 21⅝ | 67.937 | 367.284 | 19.164 | 27 | 84.823 | 572.556 | 23.927 |
| 21¾ | 68.329 | 371.543 | 19.274 | 27⅛ | 85.215 | 577.870 | 24.038 |
| 21⅞ | 68.722 | 375.826 | 19.385 | 27¼ | 85.608 | 583.208 | 24.149 |
| | | | | 27⅜ | 86.001 | 588.571 | 24.259 |
| 22 | 69.115 | 380.133 | 19.496 | 27½ | 86.394 | 593.958 | 24.370 |
| 22⅛ | 69.507 | 384.465 | 19.607 | 27⅝ | 86.786 | 599.370 | 24.481 |
| 22¼ | 69.900 | 388.822 | 19.718 | 27¾ | 87.179 | 604.807 | 24.592 |
| 22⅜ | 70.293 | 393.203 | 19.828 | 27⅞ | 87.572 | 610.268 | 24.703 |

CIRCLES—DIAMETER, CIRCUMFERENCE, AREA, ETC.—(*Cont.*)

| Diameter | Circumference | Area | Side of Equal Square (Square Root of Area) | Diameter | Circumference | Area | Side of Equal Square (Square Root of Area) |
|---|---|---|---|---|---|---|---|
| 28 | 87.964 | 615.753 | 24.813 | 33½ | 105.243 | 881.41 | 29.687 |
| 28⅛ | 88.357 | 621.263 | 24.924 | 33⅝ | 105.636 | 888.00 | 29.798 |
| 28¼ | 88.750 | 626.798 | 25.035 | 33¾ | 106.029 | 894.61 | 29.909 |
| 28⅜ | 89.142 | 632.357 | 25.146 | 33⅞ | 106.421 | 901.25 | 30.020 |
| 28½ | 89.535 | 637.941 | 25.256 | | | | |
| 28⅝ | 89.928 | 643.594 | 25.367 | 34 | 106.814 | 907.92 | 30.131 |
| 28¾ | 90.321 | 649.182 | 25.478 | 34⅛ | 107.207 | 914.61 | 30.241 |
| 28⅞ | 90.713 | 654.839 | 25.589 | 34¼ | 107.599 | 921.32 | 30.352 |
| | | | | 34⅜ | 107.992 | 928.06 | 30.463 |
| 29 | 91.106 | 660.521 | 25.699 | 34½ | 108.385 | 934.82 | 30.574 |
| 29⅛ | 91.499 | 666.227 | 25.810 | 34⅝ | 108.777 | 941.60 | 30.684 |
| 29¼ | 91.891 | 671.958 | 25.921 | 34¾ | 109.170 | 948.41 | 30.795 |
| 29⅜ | 92.284 | 677.714 | 26.032 | 34⅞ | 109.563 | 955.25 | 30.906 |
| 29½ | 92.677 | 683.494 | 26.143 | | | | |
| 29⅝ | 93.069 | 689.298 | 26.253 | 35 | 109.956 | 962.11 | 31.017 |
| 29¾ | 93.462 | 695.128 | 26.364 | 35⅛ | 110.348 | 968.99 | 31.128 |
| 29⅞ | 93.855 | 700.981 | 26.478 | 35¼ | 110.741 | 975.90 | 31.238 |
| | | | | 35⅜ | 111.134 | 982.84 | 31.349 |
| 30 | 94.248 | 706.860 | 26.586 | 35½ | 111.526 | 989.80 | 31.460 |
| 30⅛ | 94.640 | 712.762 | 26.696 | 35⅝ | 111.919 | 996.78 | 31.571 |
| 30¼ | 95.033 | 718.690 | 26.807 | 35¾ | 112.312 | 1003.78 | 31.681 |
| 30⅜ | 95.426 | 724.641 | 26.918 | 35⅞ | 112.704 | 1010.82 | 31.792 |
| 30½ | 95.818 | 730.618 | 27.029 | | | | |
| 30⅝ | 96.211 | 736.619 | 27.139 | 36 | 113.097 | 1017.87 | 31.903 |
| 30¾ | 96.604 | 742.644 | 27.250 | 36⅛ | 113.490 | 1024.95 | 32.014 |
| 30⅞ | 96.996 | 748.694 | 27.361 | 36¼ | 113.883 | 1032.06 | 32.124 |
| | | | | 36⅜ | 114.275 | 1039.19 | 32.235 |
| 31 | 97.389 | 754.769 | 27.472 | 36½ | 114.668 | 1046.35 | 32.349 |
| 31⅛ | 97.782 | 760.868 | 27.583 | 36⅝ | 115.061 | 1053.52 | 32.457 |
| 31¼ | 98.175 | 766.992 | 27.693 | 36¾ | 115.453 | 1060.73 | 32.567 |
| 31⅜ | 98.567 | 773.140 | 27.804 | 36⅞ | 115.846 | 1067.95 | 32.678 |
| 31½ | 98.968 | 779.313 | 27.915 | | | | |
| 31⅝ | 99.353 | 785.510 | 28.026 | 37 | 116.239 | 1075.21 | 32.789 |
| 31¾ | 99.745 | 791.732 | 28.136 | 37⅛ | 116.631 | 1082.48 | 32.900 |
| 31⅞ | 100.138 | 797.978 | 28.247 | 37¼ | 117.024 | 1089.79 | 33.011 |
| | | | | 37⅜ | 117.417 | 1097.11 | 33.021 |
| 32 | 100.531 | 804.249 | 28.358 | 37½ | 117.810 | 1104.46 | 33.232 |
| 32⅛ | 100.924 | 810.545 | 28.469 | 37⅝ | 118.202 | 1111.84 | 33.343 |
| 32¼ | 101.316 | 816.865 | 28.580 | 37¾ | 118.595 | 1119.24 | 33.454 |
| 32⅜ | 101.709 | 823.209 | 28.691 | 37⅞ | 118.988 | 1126.66 | 33.564 |
| 32½ | 102.102 | 829.578 | 28.801 | | | | |
| 32⅝ | 102.494 | 835.972 | 28.912 | 38 | 119.380 | 1134.11 | 33.675 |
| 32¾ | 102.887 | 842.390 | 29.023 | 38⅛ | 119.773 | 1141.59 | 33.786 |
| 32⅞ | 103.280 | 848.833 | 29.133 | 38¼ | 120.166 | 1149.08 | 33.897 |
| | | | | 38⅜ | 120.558 | 1156.61 | 34.008 |
| 33 | 103.672 | 855.30 | 29.244 | 38½ | 120.951 | 1164.15 | 34.118 |
| 33⅛ | 104.055 | 861.79 | 29.355 | 38⅝ | 121.344 | 1171.73 | 34.229 |
| 33¼ | 104.458 | 868.30 | 29.466 | 38¾ | 121.737 | 1179.32 | 34.340 |
| 33⅜ | 104.850 | 874.84 | 29.577 | 38⅞ | 122.129 | 1186.94 | 34.451 |

CIRCLES—DIAMETER, CIRCUMFERENCE, AREA, ETC.—(*Cont.*)

| Diameter | Circum-ference | Area | Side of Equal Square (Square Root of Area) | Diameter | Circum-ference | Area | Side of Equal Square (Square Root of Area) |
|---|---|---|---|---|---|---|---|
| 39 | 122.522 | 1194.59 | 34.561 | 44½ | 139.801 | 1555.28 | 39.436 |
| 39⅛ | 122.915 | 1202.26 | 34.672 | 44⅝ | 140.193 | 1564.03 | 39.546 |
| 39¼ | 123.307 | 1209.95 | 34.783 | 44¾ | 140.586 | 1572.81 | 39.657 |
| 39⅜ | 123.700 | 1217.67 | 34.894 | 44⅞ | 140.979 | 1581.61 | 39.768 |
| 39½ | 124.093 | 1225.42 | 35.005 | | | | |
| 39⅝ | 124.485 | 1233.18 | 35.115 | 45 | 141.372 | 1590.43 | 39.879 |
| 39¾ | 124.878 | 1240.98 | 35.226 | 45⅛ | 141.764 | 1599.28 | 39.989 |
| 39⅞ | 125.271 | 1248.79 | 35.337 | 45¼ | 142.157 | 1608.15 | 40.110 |
| | | | | 45⅜ | 142.550 | 1617.04 | 40.211 |
| 40 | 125.664 | 1256.64 | 35.448 | 45½ | 142.942 | 1625.97 | 40.322 |
| 40⅛ | 126.056 | 1264.50 | 35.558 | 45⅝ | 143.335 | 1634.92 | 40.432 |
| 40¼ | 126.449 | 1272.39 | 35.669 | 45¾ | 143.728 | 1643.89 | 40.543 |
| 40⅜ | 126.842 | 1280.31 | 35.780 | 45⅞ | 144.120 | 1652.88 | 40.654 |
| 40½ | 127.234 | 1288.25 | 35.891 | | | | |
| 40⅝ | 127.627 | 1296.21 | 36.002 | 46 | 144.513 | 1661.90 | 40.765 |
| 40¾ | 128.020 | 1304.20 | 36.112 | 46⅛ | 144.906 | 1670.95 | 40.876 |
| 40⅞ | 128.412 | 1312.21 | 36.223 | 46¼ | 145.299 | 1680.01 | 40.986 |
| | | | | 46⅜ | 145.691 | 1689.10 | 41.097 |
| 41 | 128.805 | 1320.25 | 36.334 | 46½ | 146.084 | 1698.23 | 41.208 |
| 41⅛ | 129.198 | 1328.32 | 36.445 | 46⅝ | 146.477 | 1707.37 | 41.319 |
| 41¼ | 129.591 | 1336.40 | 36.555 | 46¾ | 146.869 | 1716.54 | 41.429 |
| 41⅜ | 129.983 | 1344.51 | 36.666 | 46⅞ | 147.262 | 1725.73 | 41.540 |
| 41½ | 130.376 | 1352.65 | 36.777 | | | | |
| 41⅝ | 130.769 | 1360.81 | 36.888 | 47 | 147.655 | 1734.94 | 41.651 |
| 41¾ | 131.161 | 1369.00 | 36.999 | 47⅛ | 148.047 | 1744.18 | 41.762 |
| 41⅞ | 131.554 | 1377.21 | 37.109 | 47¼ | 148.440 | 1753.45 | 41.873 |
| | | | | 47⅜ | 148.833 | 1762.73 | 41.983 |
| 42 | 131.947 | 1385.44 | 37.220 | 47½ | 149.226 | 1772.05 | 42.094 |
| 42⅛ | 132.339 | 1393.70 | 37.331 | 47⅝ | 149.618 | 1781.39 | 42.205 |
| 42¼ | 132.732 | 1401.98 | 37.442 | 47¾ | 150.011 | 1790.76 | 42.316 |
| 42⅜ | 133.125 | 1410.29 | 37.552 | 47⅞ | 150.404 | 1800.14 | 42.427 |
| 42½ | 133.518 | 1418.62 | 37.663 | | | | |
| 42⅝ | 133.910 | 1426.98 | 37.774 | 48 | 150.796 | 1809.56 | 42.537 |
| 42¾ | 134.303 | 1435.36 | 37.885 | 48⅛ | 151.189 | 1818.99 | 42.648 |
| 42⅞ | 134.696 | 1443.77 | 37.996 | 48¼ | 151.582 | 1828.46 | 42.759 |
| | | | | 48⅜ | 151.974 | 1837.93 | 42.870 |
| 43 | 135.088 | 1452.20 | 38.106 | 48½ | 152.367 | 1847.45 | 42.980 |
| 43⅛ | 135.481 | 1460.65 | 38.217 | 48⅝ | 152.760 | 1856.99 | 43.091 |
| 43¼ | 135.874 | 1469.13 | 38.328 | 48¾ | 153.153 | 1866.55 | 43.202 |
| 43⅜ | 136.266 | 1477.63 | 38.439 | 48⅞ | 153.545 | 1876.13 | 43.313 |
| 43½ | 136.659 | 1486.17 | 38.549 | | | | |
| 43⅝ | 137.052 | 1494.72 | 38.660 | 49 | 153.938 | 1885.74 | 43.423 |
| 43¾ | 137.445 | 1503.30 | 38.771 | 49⅛ | 154.331 | 1895.37 | 43.534 |
| 43⅞ | 137.837 | 1511.90 | 38.882 | 49¼ | 154.723 | 1905.03 | 43.645 |
| | | | | 49⅜ | 155.116 | 1914.70 | 43.756 |
| 44 | 138.230 | 1520.53 | 38.993 | 49½ | 155.509 | 1924.42 | 43.867 |
| 44⅛ | 138.623 | 1529.18 | 39.103 | 49⅝ | 155.901 | 1934.15 | 43.977 |
| 44¼ | 139.015 | 1537.86 | 39.214 | 49¾ | 156.294 | 1943.91 | 44.088 |
| 44⅜ | 139.408 | 1546.55 | 39.325 | 49⅞ | 156.687 | 1953.69 | 44.199 |

CIRCLES—DIAMETER, CIRCUMFERENCE, AREA, ETC.—(*Cont.*)

| Diameter | Circumference | Area | Side of Equal Square (Square Root of Area) | Diameter | Circumference | Area | Side of Equal Square (Square Root of Area) |
|---|---|---|---|---|---|---|---|
| 50 | 157.080 | 1963.50 | 44.310 | 60 | 188.496 | 2827.44 | 53.172 |
| 50¼ | 157.865 | 1983.18 | 44.531 | 60¼ | 189.281 | 2851.05 | 53.393 |
| 50½ | 158.650 | 2002.96 | 44.753 | 60½ | 190.066 | 2874.76 | 53.615 |
| 50¾ | 159.436 | 2022.84 | 44.974 | 60¾ | 190.852 | 2898.56 | 53.836 |
| 51 | 160.221 | 2042.82 | 45.196 | 61 | 191.637 | 2922.47 | 54.048 |
| 51¼ | 161.007 | 2062.90 | 45.417 | 61¼ | 192.423 | 2946.47 | 54.279 |
| 51½ | 161.792 | 2083.07 | 45.639 | 61½ | 193.208 | 2970.57 | 54.501 |
| 51¾ | 162.577 | 2103.35 | 45.861 | 61¾ | 193.993 | 2994.77 | 54.723 |
| 52 | 163.363 | 2123.72 | 46.082 | 62 | 194.779 | 3019.07 | 54.944 |
| 52¼ | 164.148 | 2144.19 | 46.304 | 62¼ | 195.564 | 3043.47 | 55.166 |
| 52½ | 164.934 | 2164.75 | 46.525 | 62½ | 196.350 | 3067.96 | 55.387 |
| 52¾ | 165.719 | 2185.42 | 46.747 | 62¾ | 197.135 | 3092.56 | 55.609 |
| 53 | 166.504 | 2206.18 | 46.968 | 63 | 197.920 | 3117.25 | 55.830 |
| 53¼ | 167.290 | 2227.05 | 47.190 | 63¼ | 198.706 | 3142.04 | 56.052 |
| 53½ | 168.075 | 2248.01 | 47.411 | 63½ | 199.491 | 3166.92 | 56.273 |
| 53¾ | 168.861 | 2269.06 | 47.633 | 63¾ | 200.277 | 3191.91 | 56.495 |
| 54 | 169.646 | 2290.22 | 47.854 | 64 | 201.062 | 3216.99 | 56.716 |
| 54¼ | 170.431 | 2311.48 | 48.076 | 64¼ | 201.847 | 3242.17 | 56.938 |
| 54½ | 171.217 | 2332.83 | 48.298 | 64½ | 202.633 | 3267.46 | 57.159 |
| 54¾ | 172.002 | 2354.28 | 48.519 | 64¾ | 203.418 | 3292.83 | 57.381 |
| 55 | 172.788 | 2375.83 | 48.741 | 65 | 204.204 | 3318.31 | 57.603 |
| 55¼ | 173.573 | 2397.48 | 48.962 | 65¼ | 204.989 | 3343.88 | 57.824 |
| 55½ | 174.358 | 2419.22 | 49.184 | 65½ | 205.774 | 3369.56 | 58.046 |
| 55¾ | 175.144 | 2441.07 | 49.405 | 65¾ | 206.560 | 3395.33 | 58.267 |
| 56 | 175.929 | 2463.01 | 49.627 | 66 | 207.345 | 3421.20 | 58.489 |
| 56¼ | 176.715 | 2485.05 | 49.848 | 66¼ | 208.131 | 3447.16 | 58.710 |
| 56½ | 177.500 | 2507.19 | 50.070 | 66½ | 208.916 | 3473.23 | 58.932 |
| 56¾ | 178.285 | 2529.42 | 50.291 | 66¾ | 209.701 | 3499.39 | 59.154 |
| 57 | 179.071 | 2551.76 | 50.513 | 67 | 210.487 | 3525.66 | 59.375 |
| 57¼ | 179.856 | 2574.19 | 50.735 | 67¼ | 211.272 | 3552.01 | 59.597 |
| 57½ | 180.642 | 2596.72 | 50.956 | 67½ | 212.058 | 3578.47 | 59.818 |
| 57¾ | 181.427 | 2619.35 | 51.178 | 67¾ | 212.843 | 3605.03 | 60.040 |
| 58 | 182.212 | 2642.08 | 51.399 | 68 | 213.628 | 3631.68 | 60.261 |
| 58¼ | 182.998 | 2664.91 | 51.621 | 68¼ | 214.414 | 3658.44 | 60.483 |
| 58½ | 183.783 | 2687.83 | 51.842 | 68½ | 215.199 | 3685.29 | 60.704 |
| 58¾ | 184.569 | 2710.85 | 52.064 | 68¾ | 215.985 | 3712.24 | 60.926 |
| 59 | 185.354 | 2733.97 | 52.285 | 69 | 216.770 | 3739.28 | 61.147 |
| 59¼ | 186.139 | 2757.19 | 52.507 | 69¼ | 217.555 | 3766.43 | 61.369 |
| 59½ | 186.925 | 2780.51 | 52.729 | 69½ | 218.341 | 3793.67 | 61.591 |
| 59¾ | 187.710 | 2803.92 | 52.950 | 69¾ | 219.126 | 3821.02 | 61.812 |

CIRCLES—DIAMETER, CIRCUMFERENCE, AREA, ETC.—(*Cont.*)

| Diameter | Circumference | Area | Side of Equal Square (Square Root of Area) | Diameter | Circumference | Area | Side of Equal Square (Square Root of Area) |
|---|---|---|---|---|---|---|---|
| 70 | 219.912 | 3848.46 | 62.034 | 80 | 251.328 | 5026.56 | 70.896 |
| 70¼ | 220.697 | 3875.99 | 62.255 | 80¼ | 252.113 | 5058.00 | 71.118 |
| 70½ | 221.482 | 3903.63 | 62.477 | 80½ | 252.898 | 5089.58 | 71.339 |
| 70¾ | 222.268 | 3931.36 | 62.698 | 80¾ | 253.683 | 5121.22 | 71.561 |
| 71 | 223.053 | 3959.20 | 62.920 | 81 | 254.469 | 5153.00 | 71.782 |
| 71¼ | 223.839 | 3987.13 | 63.141 | 81¼ | 255.254 | 5184.84 | 72.004 |
| 71½ | 224.624 | 4015.16 | 63.363 | 81½ | 256.040 | 5216.82 | 72.225 |
| 71¾ | 225.409 | 4043.28 | 63.545 | 81¾ | 256.825 | 5248.84 | 72.447 |
| 72 | 226.195 | 4071.51 | 63.806 | 82 | 257.611 | 5281.02 | 72.668 |
| 72¼ | 226.980 | 4099.83 | 64.028 | 82¼ | 258.396 | 5313.28 | 72.890 |
| 72½ | 227.766 | 4128.25 | 64.249 | 82½ | 259.182 | 5345.62 | 73.111 |
| 72¾ | 228.551 | 4156.77 | 64.471 | 82¾ | 259.967 | 5378.04 | 73.333 |
| 73 | 229.336 | 4185.39 | 64.692 | 83 | 260.752 | 5410.62 | 73.554 |
| 73¼ | 230.122 | 4214.11 | 64.914 | 83¼ | 261.537 | 5443.24 | 73.776 |
| 73½ | 230.907 | 4242.92 | 65.135 | 83½ | 262.323 | 5476.00 | 73.997 |
| 73¾ | 231.693 | 4271.83 | 65.357 | 83¾ | 263.108 | 5508.84 | 74.219 |
| 74 | 232.478 | 4300.85 | 65.578 | 84 | 263.894 | 5541.78 | 74.440 |
| 74¼ | 233.263 | 4329.95 | 65.800 | 84¼ | 264.679 | 5574.80 | 74.662 |
| 74½ | 234.049 | 4359.16 | 66.022 | 84½ | 265.465 | 5607.95 | 74.884 |
| 74¾ | 234.834 | 4388.47 | 66.243 | 84¾ | 266.250 | 5641.16 | 75.106 |
| 75 | 235.620 | 4417.87 | 66.465 | 85 | 267.036 | 5674.51 | 75.327 |
| 75¼ | 236.405 | 4447.37 | 66.686 | 85¼ | 267.821 | 5707.92 | 75.549 |
| 75½ | 237.190 | 4476.97 | 66.908 | 85½ | 268.606 | 5741.47 | 75.770 |
| 75¾ | 237.976 | 4506.67 | 67.129 | 85¾ | 269.392 | 5775.09 | 75.992 |
| 76 | 238.761 | 4536.47 | 67.351 | 86 | 270.177 | 5808.81 | 76.213 |
| 76¼ | 239.547 | 4566.36 | 67.572 | 86¼ | 270.962 | 5842.60 | 76.435 |
| 76½ | 240.332 | 4596.35 | 67.794 | 86½ | 271.748 | 5876.55 | 76.656 |
| 76¾ | 241.117 | 4626.44 | 68.016 | 86¾ | 272.533 | 5910.52 | 76.878 |
| 77 | 241.903 | 4656.63 | 68.237 | 87 | 273.319 | 5944.69 | 77.099 |
| 77¼ | 242.688 | 4686.92 | 68.459 | 87¼ | 274.104 | 5978.88 | 77.321 |
| 77½ | 243.474 | 4717.30 | 68.680 | 87½ | 274.890 | 6013.21 | 77.542 |
| 77¾ | 244.259 | 4747.79 | 68.902 | 87¾ | 275.675 | 6047.60 | 77.764 |
| 78 | 245.044 | 4778.37 | 69.123 | 88 | 276.460 | 6082.13 | 77.985 |
| 78¼ | 245.830 | 4809.05 | 69.345 | 88¼ | 277.245 | 6116.72 | 78.207 |
| 78½ | 246.615 | 4839.83 | 69.566 | 88½ | 278.031 | 6151.44 | 78.428 |
| 78¾ | 247.401 | 4870.70 | 69.788 | 88¾ | 278.816 | 6186.20 | 78.650 |
| 79 | 248.186 | 4901.68 | 70.009 | 89 | 279.602 | 6221.15 | 78.871 |
| 79¼ | 248.971 | 4932.75 | 70.231 | 89¼ | 280.387 | 6256.12 | 79.093 |
| 79½ | 249.757 | 4963.92 | 70.453 | 89½ | 281.173 | 6291.25 | 79.315 |
| 79¾ | 250.542 | 4995.19 | 70.674 | 89¾ | 281.958 | 6326.44 | 79.537 |

CIRCLES—DIAMETER, CIRCUMFERENCE, AREA, ETC.—(*Cont.*)

| Diameter | Circumference | Area | Side of Equal Square (Square Root of Area) | Diameter | Circumference | Area | Side of Equal Square (Square Root of Area) |
|---|---|---|---|---|---|---|---|
| 90 | 282.744 | 6361.74 | 79.758 | 101 | 317.301 | 8011.84 | 89.509 |
| 90¼ | 283.529 | 6399.12 | 79.980 | 101½ | 318.872 | 8091.36 | 89.952 |
| 90½ | 284.314 | 6432.62 | 80.201 | 102 | 320.442 | 8171.28 | 90.395 |
| 90¾ | 285.099 | 6468.16 | 80.423 | 102½ | 322.014 | 8251.60 | 90.838 |
| 91 | 285.885 | 6503.89 | 80.644 | 103 | 323.584 | 8332.29 | 91.282 |
| 91¼ | 286.670 | 6539.68 | 80.866 | 103½ | 325.154 | 8413.40 | 91.725 |
| 91½ | 287.456 | 6573.56 | 81.087 | 104 | 326.726 | 8494.87 | 92.168 |
| 91¾ | 288.242 | 6611.52 | 81.308 | 104½ | 328.296 | 8576.76 | 92.611 |
| 92 | 289.027 | 6647.62 | 81.530 | 105 | 329.867 | 8659.01 | 93.054 |
| 92¼ | 289.812 | 6683.80 | 81.752 | 105½ | 331.438 | 8741.68 | 93.497 |
| 92½ | 290.598 | 6720.07 | 81.973 | 106 | 333.009 | 8824.73 | 93.940 |
| 92¾ | 291.383 | 6756.40 | 82.195 | 106½ | 334.580 | 8908.20 | 94.383 |
| 93 | 292.168 | 6792.92 | 82.416 | 107 | 336.150 | 8992.02 | 94.826 |
| 93¼ | 292.953 | 6829.48 | 82.638 | 107½ | 337.722 | 9076.24 | 95.269 |
| 93½ | 293.739 | 6866.16 | 82.859 | 108 | 339.292 | 9160.88 | 95.713 |
| 93¾ | 294.524 | 6882.92 | 83.081 | 108½ | 340.862 | 9245.92 | 96.156 |
| 94 | 295.310 | 6939.79 | 83.302 | 109 | 342.434 | 9331.32 | 96.599 |
| 94¼ | 296.095 | 6976.72 | 83.524 | 109½ | 344.004 | 9417.12 | 97.042 |
| 94½ | 296.881 | 7013.81 | 83.746 | 110 | 345.575 | 9503.32 | 97.485 |
| 94¾ | 297.666 | 7050.92 | 83.968 | 110½ | 347.146 | 9589.92 | 97.928 |
| 95 | 298.452 | 7088.23 | 84.189 | 111 | 348.717 | 9676.89 | 98.371 |
| 95¼ | 299.237 | 7125.56 | 84.411 | 111½ | 350.288 | 9764.28 | 98.815 |
| 95½ | 300.022 | 7163.04 | 84.632 | 112 | 351.858 | 9852.03 | 99.258 |
| 95¾ | 300.807 | 7200.56 | 84.854 | 112½ | 353.430 | 9940.20 | 99.701 |
| 96 | 301.593 | 7238.24 | 85.077 | 113 | 355.000 | 10028.75 | 100.144 |
| 96¼ | 302.378 | 7275.96 | 85.299 | 113½ | 356.570 | 10117.68 | 100.587 |
| 96½ | 302.164 | 7313.84 | 85.520 | 114 | 358.142 | 10207.03 | 101.031 |
| 96¾ | 303.948 | 7351.82 | 85.742 | 114½ | 359.712 | 10296.76 | 101.474 |
| 97 | 304.734 | 7389.80 | 85.963 | 115 | 361.283 | 10386.89 | 101.917 |
| 97¼ | 305.520 | 7427.96 | 86.185 | 115½ | 362.854 | 10477.40 | 102.360 |
| 97½ | 306.306 | 7474.20 | 86.407 | 116 | 364.425 | 10568.32 | 102.803 |
| 97¾ | 307.090 | 7504.52 | 86.628 | 116½ | 365.996 | 10659.64 | 103.247 |
| 98 | 307.876 | 7452.96 | 86.850 | 117 | 367.566 | 10751.32 | 103.690 |
| 98¼ | 308.662 | 7581.48 | 87.072 | 117½ | 369.138 | 10843.40 | 104.133 |
| 98½ | 309.446 | 7620.12 | 87.293 | 118 | 370.708 | 10935.88 | 104.576 |
| 98¾ | 310.232 | 7658.80 | 87.515 | 118½ | 372.278 | 11028.76 | 105.019 |
| 99 | 311.018 | 7697.68 | 87.736 | 119 | 373.849 | 11122.02 | 105.463 |
| 99¼ | 311.802 | 7736.60 | 87.958 | 119½ | 375.420 | 11215.68 | 105.906 |
| 99½ | 312.588 | 7775.64 | 88.180 | 120 | 376.991 | 11309.73 | 106.350 |
| 99¾ | 313.374 | 7814.76 | 88.401 | | | | |
| 100 | 314.159 | 7854.00 | 88.623 | | | | |
| 100½ | 315.730 | 7932.72 | 89.066 | | | | |

Numbers, Diameters and Areas of Circles, Squares, Cubes, Square and Cube Roots from 1 to 1,000

| Number or Diameter | Circumference | Circular Area | Square | Cube | Square Root | Cube Root | Reciprocal |
|---|---|---|---|---|---|---|---|
| 1 | 3.1416 | 0.7854 | 1 | 1 | 1.000 | 1.000 | 1.000000 |
| 2 | 6.28 | 3.14 | 4 | 8 | 1.414 | 1.259 | .500000 |
| 3 | 9.42 | 7.07 | 9 | 27 | 1.732 | 1.442 | .333333 |
| 4 | 12.57 | 12.57 | 16 | 64 | 2.000 | 1.587 | .250000 |
| 5 | 15.71 | 19.63 | 25 | 125 | 2.236 | 1.709 | .200000 |
| 6 | 18.85 | 28.27 | 36 | 216 | 2.449 | 1.817 | .166667 |
| 7 | 21.99 | 38.48 | 49 | 343 | 2.645 | 1.912 | .142857 |
| 8 | 25.13 | 50.26 | 64 | 512 | 2.828 | 2.000 | .125000 |
| 9 | 28.27 | 63.61 | 81 | 729 | 3.000 | 2.080 | .111111 |
| 10 | 31.42 | 78.54 | 100 | 1,000 | 3.162 | 2.154 | .100000 |
| 11 | 34.55 | 95.03 | 121 | 1,331 | 3.316 | 2.223 | .090909 |
| 12 | 37.69 | 113.09 | 144 | 1,728 | 3.464 | 2.289 | .083333 |
| 13 | 40.84 | 132.73 | 169 | 2,197 | 3.605 | 2.351 | .076923 |
| 14 | 43.98 | 153.93 | 196 | 2,744 | 3.741 | 2.410 | .071429 |
| 15 | 47.12 | 173.71 | 225 | 3,375 | 3.872 | 2.466 | .066667 |
| 16 | 50.26 | 201.06 | 256 | 4,096 | 4.000 | 2.519 | .062500 |
| 17 | 53.40 | 226.98 | 289 | 4,913 | 4.123 | 2.571 | .058824 |
| 18 | 56.54 | 254.46 | 324 | 5,832 | 4.232 | 2.620 | .055556 |
| 19 | 59.69 | 283.52 | 361 | 6,859 | 4.358 | 2.668 | .052632 |
| 20 | 62.83 | 314.15 | 400 | 8,000 | 4.472 | 2.714 | .050000 |
| 21 | 65.97 | 346.36 | 441 | 9,261 | 4.582 | 2.758 | .047619 |
| 22 | 69.11 | 380.13 | 484 | 10,648 | 4.690 | 2.802 | .045455 |
| 23 | 72.25 | 415.47 | 529 | 12,167 | 4.795 | 2.843 | .043478 |
| 24 | 75.39 | 452.38 | 576 | 13,824 | 4.898 | 2.884 | .041667 |
| 25 | 78.54 | 490.87 | 625 | 15,625 | 5.000 | 2.924 | .040000 |
| 26 | 81.68 | 530.02 | 676 | 17,576 | 5.099 | 2.962 | .038462 |
| 27 | 84.82 | 572.55 | 729 | 19,683 | 5.196 | 3.000 | .037037 |
| 28 | 87.96 | 615.75 | 784 | 21,952 | 5.291 | 3.036 | .035714 |
| 29 | 91.10 | 660.52 | 841 | 24,389 | 5.385 | 3.072 | .034483 |
| 30 | 94.24 | 706.85 | 900 | 27,000 | 5.477 | 3.107 | .033333 |
| 31 | 97.38 | 754.76 | 961 | 29,791 | 5.567 | 3.141 | .032258 |
| 32 | 100.53 | 804.24 | 1,024 | 32,768 | 5.656 | 3.174 | .031250 |
| 33 | 103.67 | 855.29 | 1,089 | 35,937 | 5.744 | 3.207 | .030303 |
| 34 | 106.81 | 907.92 | 1,156 | 39,304 | 5.830 | 3.239 | .029412 |
| 35 | 109.95 | 962.11 | 1,225 | 42,875 | 5.916 | 3.271 | .028571 |
| 36 | 113.09 | 1017.87 | 1,296 | 46,656 | 6.000 | 3.301 | .027778 |
| 37 | 116.23 | 1075.21 | 1,369 | 50,653 | 6.082 | 3.332 | .027027 |
| 38 | 119.38 | 1134.11 | 1,444 | 54,872 | 6.164 | 3.361 | .026316 |
| 39 | 122.52 | 1194.59 | 1,521 | 59,319 | 6.244 | 3.391 | .025641 |
| 40 | 125.66 | 1256.63 | 1,600 | 64,000 | 6.324 | 3.419 | .025000 |
| 41 | 128.80 | 1320.25 | 1,681 | 68,921 | 6.403 | 3.448 | .024390 |
| 42 | 131.94 | 1385.44 | 1,764 | 74,088 | 6.480 | 3.476 | .023810 |
| 43 | 135.08 | 1452.20 | 1,849 | 79,507 | 6.557 | 3.503 | .023256 |
| 44 | 138.23 | 1520.52 | 1,936 | 85,184 | 6.633 | 3.530 | .022727 |
| 45 | 141.37 | 1590.43 | 2,025 | 91,215 | 6.708 | 3.556 | .022222 |

NUMBERS, DIAMETERS AND AREAS, ETC.—(*Cont.*)

| Number or Diameter | Circumference | Circular Area | Square | Cube | Square Root | Cube Root | Reciprocal |
|---|---|---|---|---|---|---|---|
| 46 | 144.51 | 1661.90 | 2,116 | 97,336 | 6.782 | 3.583 | .021739 |
| 47 | 147.65 | 1734.94 | 2,209 | 103,823 | 6.855 | 3.608 | .021277 |
| 48 | 150.79 | 1809.55 | 2,304 | 110,592 | 6.928 | 3.634 | .020833 |
| 49 | 153.93 | 1885.74 | 2,401 | 117,649 | 7.000 | 3.659 | .020408 |
| 50 | 157.08 | 1963.49 | 2,500 | 125,000 | 7.071 | 3.684 | .020000 |
| 51 | 160.22 | 2042.82 | 2,601 | 132,651 | 7.141 | 3.708 | .019608 |
| 52 | 163.36 | 2123.71 | 2,704 | 140,608 | 7.211 | 3.732 | .019231 |
| 53 | 166.50 | 2206.18 | 2,809 | 148,877 | 7.280 | 3.756 | .018868 |
| 54 | 169.64 | 2290.21 | 2,916 | 157,464 | 7.348 | 3.779 | .018519 |
| 55 | 172.78 | 2375.82 | 3,025 | 166,375 | 7.416 | 3.802 | .018182 |
| 56 | 175.92 | 2463.09 | 3,136 | 175,616 | 7.483 | 3.825 | .017857 |
| 57 | 179.07 | 2551.75 | 3,249 | 185,193 | 7.549 | 3.848 | .017544 |
| 58 | 182.21 | 2642.08 | 3,364 | 195,112 | 7.615 | 3.870 | .017241 |
| 59 | 185.35 | 2733.97 | 3,481 | 205,379 | 7.681 | 3.892 | .016949 |
| 60 | 188.49 | 2827.43 | 3,600 | 216,000 | 7.745 | 3.914 | .016667 |
| 61 | 191.63 | 2922.46 | 3,721 | 226,981 | 7.810 | 3.936 | .016393 |
| 62 | 194.77 | 3019.07 | 3,844 | 238,328 | 7.874 | 3.957 | .016129 |
| 63 | 197.92 | 3117.24 | 3,969 | 250,047 | 7.937 | 3.979 | .015873 |
| 64 | 201.06 | 3216.99 | 4,096 | 262,144 | 8.000 | 4.000 | .015625 |
| 65 | 204.20 | 3318.30 | 4,225 | 274,625 | 8.062 | 4.020 | .015385 |
| 66 | 207.34 | 3421.18 | 4,356 | 287,496 | 8.124 | 4.041 | .015152 |
| 67 | 210.48 | 3525.65 | 4,489 | 300,763 | 8.185 | 4.061 | .014925 |
| 68 | 213.62 | 3631.68 | 4,624 | 314,432 | 8.246 | 4.081 | .014706 |
| 69 | 216.77 | 3739.28 | 4,761 | 328,509 | 8.306 | 4.101 | .014493 |
| 70 | 219.91 | 3848.45 | 4,900 | 343,000 | 8.366 | 4.121 | .014286 |
| 71 | 223.05 | 3959.19 | 5,041 | 357,911 | 8.426 | 4.140 | .014085 |
| 72 | 226.19 | 4071.50 | 5,184 | 373,248 | 8.485 | 4.160 | .013889 |
| 73 | 229.33 | 4185.38 | 5,329 | 389,017 | 8.544 | 4.179 | .013699 |
| 74 | 232.47 | 4300.84 | 5,476 | 405,224 | 8.602 | 4.198 | .013514 |
| 75 | 235.61 | 4417.86 | 5,625 | 421,875 | 8.660 | 4.217 | .013333 |
| 76 | 238.76 | 4536.45 | 5,776 | 438,976 | 8.717 | 4.235 | .013158 |
| 77 | 241.90 | 4656.62 | 5,929 | 456,533 | 8.744 | 4.254 | .012987 |
| 78 | 245.04 | 4778.36 | 6,084 | 474,552 | 8.831 | 4.272 | .012821 |
| 79 | 248.18 | 4901.66 | 6,241 | 493,039 | 8.888 | 4.290 | .012658 |
| 80 | 251.32 | 5026.54 | 6,400 | 512,000 | 8.944 | 4.308 | .012500 |
| 81 | 254.46 | 5153.00 | 6,561 | 531,441 | 9.000 | 4.326 | .012346 |
| 82 | 257.61 | 5281.01 | 6,724 | 551,368 | 9.055 | 4.344 | .012195 |
| 83 | 260.75 | 5410.59 | 6,889 | 571,787 | 9.110 | 4.362 | .012048 |
| 84 | 263.89 | 5541.77 | 7,056 | 592,704 | 9.165 | 4.379 | .011905 |
| 85 | 267.03 | 5674.50 | 7,225 | 614,125 | 9.219 | 4.396 | .011765 |
| 86 | 270.17 | 5808.80 | 7,396 | 636,056 | 9.273 | 4.414 | .011628 |
| 87 | 273.31 | 5944.67 | 7,569 | 658,503 | 9.327 | 4.431 | .011494 |
| 88 | 276.46 | 6082.11 | 7,744 | 681,472 | 9.380 | 4.447 | .011364 |
| 89 | 279.60 | 6221.13 | 7,921 | 704,969 | 9.433 | 4.461 | .011236 |
| 90 | 282.74 | 6361.72 | 8,100 | 729,000 | 9.486 | 4.481 | .011111 |

NUMBERS, DIAMETERS AND AREAS, ETC.—(*Cont.*)

| Number or Diameter | Circumference | Circular Area | Square | Cube | Square Root | Cube Root | Reciprocal |
|---|---|---|---|---|---|---|---|
| 91 | 285.88 | 6503.87 | 8,281 | 753,571 | 9.539 | 4.497 | .010989 |
| 92 | 289.02 | 6647.61 | 8,464 | 778,688 | 9.591 | 4.514 | .010870 |
| 93 | 292.16 | 6792.90 | 8,649 | 804,357 | 9.643 | 4.530 | .010753 |
| 94 | 295.31 | 6939.78 | 8,836 | 830,584 | 9.695 | 4.546 | .010638 |
| 95 | 298.45 | 7088.21 | 9,025 | 857,375 | 9.746 | 4.562 | .010526 |
| 96 | 301.59 | 7238.23 | 9,216 | 884,736 | 9.797 | 4.578 | .010417 |
| 97 | 304.73 | 7389.81 | 9,409 | 912,673 | 9.848 | 4.594 | .010309 |
| 98 | 307.87 | 7542.96 | 9,604 | 941,192 | 9.899 | 4.610 | .010204 |
| 99 | 311.01 | 7697.68 | 9,801 | 970,299 | 9.949 | 4.626 | .010101 |
| 100 | 314.15 | 7853.97 | 10,000 | 1,000,000 | 10.000 | 4.641 | .010000 |
| 101 | 317.30 | 8011.86 | 10,201 | 1,030,301 | 10.049 | 4.657 | .009901 |
| 102 | 320.41 | 8171.30 | 10,404 | 1,061,208 | 10.099 | 4.672 | .009804 |
| 103 | 323.58 | 8332.30 | 10,609 | 1,092,727 | 10.148 | 4.687 | .009709 |
| 104 | 326.72 | 8494.88 | 10,816 | 1,124,864 | 10.198 | 4.702 | .009615 |
| 105 | 329.86 | 8659.03 | 11,025 | 1,157,625 | 10.246 | 4.717 | .009524 |
| 106 | 333.00 | 8824.75 | 11,236 | 1,191,016 | 10.295 | 4.732 | .009434 |
| 107 | 336.15 | 8992.04 | 11,449 | 1,225,043 | 10.344 | 4.747 | .009346 |
| 108 | 339.29 | 9160.90 | 11,664 | 1,259,712 | 10.392 | 4.762 | .009259 |
| 109 | 342.43 | 9331.33 | 11,881 | 1,295,029 | 10.440 | 4.776 | .009174 |
| 110 | 345.57 | 9503.34 | 12,100 | 1,331,000 | 10.488 | 4.791 | .009091 |
| 111 | 348.71 | 9676.91 | 12,321 | 1,367,631 | 10.535 | 4.805 | .009009 |
| 112 | 351.85 | 9852.05 | 12,544 | 1,404,928 | 10.583 | 4.820 | .008929 |
| 113 | 355.01 | 10028.77 | 12,759 | 1,442,897 | 10.630 | 4.834 | .008850 |
| 114 | 358.14 | 10207.05 | 12,996 | 1,481,544 | 10.677 | 4.848 | .008772 |
| 115 | 361.28 | 10386.91 | 13,225 | 1,520,875 | 10.723 | 4.862 | .008696 |
| 116 | 364.42 | 10568.34 | 13,456 | 1,560,896 | 10.770 | 4.876 | .008621 |
| 117 | 367.56 | 10751.34 | 13,689 | 1,601,613 | 10.816 | 4.890 | .008547 |
| 118 | 370.70 | 10935.90 | 13,924 | 1,643,032 | 10.862 | 4.904 | .008475 |
| 119 | 373.81 | 11122.04 | 14,161 | 1,685,159 | 10.908 | 4.918 | .008403 |
| 120 | 376.99 | 11309.76 | 14,400 | 1,728,000 | 10.954 | 4.932 | .008333 |
| 121 | 380.13 | 11499.04 | 14,641 | 1,771,561 | 11.000 | 4.946 | .008264 |
| 122 | 383.27 | 11689.89 | 14,884 | 1,815,848 | 11.045 | 4.959 | .008197 |
| 123 | 386.41 | 11882.31 | 15,129 | 1,860,867 | 11.090 | 4.973 | .008130 |
| 124 | 389.55 | 12076.31 | 15,376 | 1,906,624 | 11.135 | 4.986 | .008065 |
| 125 | 392.70 | 12271.87 | 15,625 | 1,953,125 | 11.180 | 5.000 | .008000 |
| 126 | 395.84 | 12469.01 | 15,876 | 2,000,376 | 11.224 | 5.013 | .007937 |
| 127 | 398.98 | 12667.71 | 16,129 | 2,048,383 | 11.269 | 5.026 | .007874 |
| 128 | 402.12 | 12867.99 | 16,384 | 2,097,152 | 11.313 | 5.039 | .007813 |
| 129 | 405.26 | 13069.84 | 16,641 | 2,146,689 | 11.357 | 5.052 | .007752 |
| 130 | 408.10 | 13273.26 | 16,900 | 2,197,000 | 11.401 | 5.065 | .007692 |
| 131 | 411.54 | 13478.24 | 17,161 | 2,248,091 | 11.445 | 5.078 | .007634 |
| 132 | 414.69 | 13694.80 | 17,424 | 2,299,968 | 11.489 | 5.091 | .007576 |
| 133 | 417.83 | 13892.94 | 17,689 | 2,352,637 | 11.532 | 5.104 | .007519 |
| 134 | 420.97 | 14102.64 | 17,956 | 2,406,104 | 11.575 | 5.117 | .007463 |
| 135 | 424.11 | 14313.91 | 18,225 | 2,460,375 | 11.618 | 5.129 | .007407 |

NUMBERS, DIAMETERS AND AREAS, ETC.—(*Cont.*)

| Number or Diameter | Circumference | Circular Area | Square | Cube | Square Root | Cube Root | Reciprocal |
|---|---|---|---|---|---|---|---|
| 136 | 427.25 | 14526.75 | 18,496 | 2,515,456 | 11.661 | 5.142 | .007353 |
| 137 | 430.39 | 14741.17 | 18,769 | 2,571,353 | 11.704 | 5.155 | .007299 |
| 138 | 433.54 | 14957.15 | 19,044 | 2,620,872 | 11.747 | 5.167 | .007246 |
| 139 | 436.68 | 15174.71 | 19,321 | 2,685,619 | 11.789 | 5.180 | .007194 |
| 140 | 439.82 | 15393.84 | 19,600 | 2,744,000 | 11.832 | 5.192 | .007143 |
| 141 | 442.96 | 15614.53 | 19,881 | 2,803,221 | 11.874 | 5.204 | .007092 |
| 142 | 446.10 | 15836.80 | 20,164 | 2,863,288 | 11.916 | 5.217 | .007042 |
| 143 | 449.24 | 16060.64 | 20,449 | 2,924,207 | 11.958 | 5.229 | .006993 |
| 144 | 452.39 | 16286.05 | 20,736 | 2,985,984 | 12.000 | 5.241 | .006944 |
| 145 | 455.53 | 16513.03 | 21,025 | 3,048,625 | 12.041 | 5.253 | .006897 |
| 146 | 458.67 | 16741.58 | 21,316 | 3,112,136 | 12.083 | 5.265 | .006849 |
| 147 | 461.81 | 16971.70 | 21,609 | 3,176,523 | 12.124 | 5.277 | .006803 |
| 148 | 464.95 | 17203.40 | 21,904 | 3,241,792 | 12.165 | 5.289 | .006757 |
| 149 | 468.09 | 17436.66 | 22,201 | 3,307,949 | 12.206 | 5.301 | .006711 |
| 150 | 471.24 | 17671.50 | 22,500 | 3,375,000 | 12.247 | 5.313 | .006667 |
| 151 | 474.38 | 17907.90 | 22,801 | 3,442,951 | 12.288 | 5.325 | .006623 |
| 152 | 477.52 | 18145.88 | 23,104 | 3,511,808 | 12.328 | 5.336 | .006579 |
| 153 | 480.66 | 18385.42 | 23,409 | 3,581,577 | 12.369 | 5.348 | .006536 |
| 154 | 483.80 | 18626.54 | 23,716 | 3,652,264 | 12.409 | 5.360 | .006494 |
| 155 | 486.94 | 18869.23 | 24,025 | 3,723,875 | 12.449 | 5.371 | .006452 |
| 156 | 490.08 | 19113.49 | 24,336 | 3,796,416 | 12.489 | 5.383 | .006410 |
| 157 | 493.23 | 19359.32 | 24,649 | 3,869,893 | 12.529 | 5.394 | .006369 |
| 158 | 496.37 | 19606.72 | 24,964 | 3,944,312 | 12.569 | 5.406 | .006329 |
| 159 | 499.51 | 19855.69 | 25,281 | 4,019,679 | 12.609 | 5.417 | .006289 |
| 160 | 502.65 | 20106.24 | 25,600 | 4,096,000 | 12.649 | 5.428 | .006250 |
| 161 | 505.79 | 20358.35 | 25,921 | 4,173,281 | 12.688 | 5.440 | .006211 |
| 162 | 508.93 | 20612.03 | 26,244 | 4,251,528 | 12.727 | 5.451 | .006173 |
| 163 | 512.08 | 20867.20 | 26,569 | 4,330,747 | 12.767 | 5.462 | .006135 |
| 164 | 515.22 | 21124.11 | 26,896 | 4,410,944 | 12.806 | 5.473 | .006098 |
| 165 | 518.36 | 21382.51 | 27,225 | 4,492,125 | 12.845 | 5.484 | .006061 |
| 166 | 521.50 | 21642.48 | 27,556 | 4,574,296 | 12.884 | 5.495 | .006024 |
| 167 | 524.64 | 21904.02 | 27,889 | 4,657,463 | 12.922 | 5.506 | .005988 |
| 168 | 527.78 | 22167.12 | 28,224 | 4,741,632 | 12.961 | 5.517 | .005952 |
| 169 | 530.93 | 22431.80 | 28,561 | 4,826,809 | 13.000 | 5.528 | .005917 |
| 170 | 534.07 | 22698.06 | 28,900 | 4,913,000 | 13.038 | 5.539 | .005882 |
| 171 | 537.31 | 22965.88 | 29,241 | 5,000,211 | 13.076 | 5.550 | .005848 |
| 172 | 540.35 | 23235.27 | 29,584 | 5,088,448 | 13.114 | 5.561 | .005814 |
| 173 | 543.49 | 23506.23 | 29,929 | 5,177,717 | 13.152 | 5.572 | .005780 |
| 174 | 546.03 | 23778.77 | 30,276 | 5,268,024 | 13.190 | 5.582 | .005747 |
| 175 | 549.78 | 24052.87 | 30,625 | 5,359,375 | 13.228 | 5.593 | .005714 |
| 176 | 552.92 | 24328.55 | 30,976 | 5,451,776 | 13.266 | 5.604 | .005682 |
| 177 | 556.06 | 24605.79 | 31,329 | 5,545,233 | 13.304 | 5.614 | .005650 |
| 178 | 559.20 | 24884.61 | 31,684 | 5,639,752 | 13.341 | 5.625 | .005618 |
| 179 | 562.34 | 25165.00 | 32,041 | 5,735,339 | 13.379 | 5.635 | .005587 |
| 180 | 565.48 | 25446.96 | 32,400 | 5,832,000 | 13.416 | 5.646 | .005556 |

NUMBERS, DIAMETERS AND AREAS, ETC.—(*Cont.*)

| Number or Diameter | Circumference | Circular Area | Square | Cube | Square Root | Cube Root | Reciprocal |
|---|---|---|---|---|---|---|---|
| 181 | 568.62 | 25730.48 | 32,761 | 5,929,741 | 13.453 | 5.656 | .005525 |
| 182 | 571.77 | 26015.58 | 33,124 | 6,028,568 | 13.490 | 5.667 | .005495 |
| 183 | 574.91 | 26302.26 | 33,489 | 6,128,487 | 13.527 | 5.677 | .005464 |
| 184 | 578.05 | 26590.50 | 33,856 | 6,229,504 | 13.564 | 5.687 | .005435 |
| 185 | 581.19 | 26880.31 | 34,225 | 6,331,625 | 13.601 | 5.698 | .005405 |
| 186 | 584.33 | 27171.69 | 34,596 | 6,434,856 | 13.638 | 5.708 | .005376 |
| 187 | 587.47 | 27464.65 | 34,969 | 6,539,203 | 13.674 | 5.718 | .005348 |
| 188 | 590.62 | 27759.17 | 35,344 | 6,644,672 | 13.711 | 5.728 | .005319 |
| 189 | 593.76 | 28055.27 | 35,721 | 6,751,269 | 13.747 | 5.738 | .005291 |
| 190 | 596.90 | 28352.94 | 36,100 | 6,859,000 | 13.784 | 5.748 | .005263 |
| 191 | 600.04 | 28652.17 | 36,481 | 6,967,871 | 13.820 | 5.758 | .005236 |
| 192 | 603.18 | 28952.98 | 36,864 | 7,077,888 | 13.856 | 5.768 | .005208 |
| 193 | 606.32 | 29255.36 | 37,249 | 7,189,057 | 13.892 | 5.778 | .005181 |
| 194 | 609.47 | 29559.31 | 37,636 | 7,301,384 | 13.928 | 5.788 | .005155 |
| 195 | 612.61 | 29864.83 | 38,025 | 7,414,875 | 13.964 | 5.798 | .005128 |
| 196 | 615.75 | 30171.92 | 38,416 | 7,529,536 | 14.000 | 5.808 | .005102 |
| 197 | 618.89 | 30480.60 | 38,809 | 7,645,373 | 14.035 | 5.818 | .005076 |
| 198 | 622.03 | 30790.82 | 39,204 | 7,762,392 | 14.071 | 5.828 | .005051 |
| 199 | 625.17 | 31102.52 | 39,601 | 7,880,599 | 14.106 | 5.838 | .005025 |
| 200 | 628.32 | 31416.00 | 40,000 | 8,000,000 | 14.142 | 5.848 | .005000 |
| 201 | 631.46 | 31730.94 | 40,401 | 8,120,601 | 14.177 | 5.857 | .004975 |
| 202 | 634.60 | 32047.46 | 40,804 | 8,242,408 | 14.212 | 5.867 | .004950 |
| 203 | 637.74 | 32365.54 | 41,209 | 8,365,427 | 14.247 | 5.877 | .004926 |
| 204 | 640.88 | 32685.20 | 41,616 | 8,489,664 | 14.282 | 5.886 | .004902 |
| 205 | 644.02 | 33006.43 | 42,025 | 8,615,125 | 14.317 | 5.896 | .004878 |
| 206 | 647.16 | 33329.23 | 42,436 | 8,741,816 | 14.352 | 5.905 | .004854 |
| 207 | 650.31 | 33653.60 | 42,849 | 8,869,743 | 14.387 | 5.915 | .004831 |
| 208 | 653.45 | 33979.54 | 43,264 | 8,998,912 | 14.422 | 5.924 | .004808 |
| 209 | 656.59 | 34307.05 | 43,681 | 9,123,329 | 14.456 | 5.934 | .004785 |
| 210 | 659.73 | 34636.14 | 44,100 | 9,261,000 | 14.491 | 5.943 | .004762 |
| 211 | 662.87 | 34966.79 | 44,521 | 9,393,931 | 14.525 | 5.953 | .004739 |
| 212 | 666.01 | 35299.01 | 44,944 | 9,528,128 | 14.560 | 5.962 | .004717 |
| 213 | 669.16 | 35632.81 | 45,369 | 9,663,597 | 14.594 | 5.972 | .004695 |
| 214 | 672.30 | 35968.17 | 45,796 | 9,800,344 | 14.628 | 5.981 | .004673 |
| 215 | 675.44 | 36305.11 | 46,225 | 9,938,375 | 14.662 | 5.990 | .004651 |
| 216 | 678.58 | 36643.62 | 46,656 | 10,077,696 | 14.696 | 6.000 | .004630 |
| 217 | 681.72 | 36983.70 | 47,089 | 10,218,313 | 14.730 | 6.009 | .004608 |
| 218 | 684.86 | 37325.34 | 47,524 | 10,360,232 | 14.764 | 6.018 | .004587 |
| 219 | 688.01 | 37668.56 | 47,961 | 10,503,459 | 14.798 | 6.027 | .004566 |
| 220 | 691.15 | 38013.36 | 48,400 | 10,648,000 | 14.832 | 6.036 | .004545 |
| 221 | 694.29 | 38359.72 | 48,841 | 10,793,861 | 14.866 | 6.045 | .004525 |
| 222 | 697.43 | 38707.65 | 49,284 | 10,941,048 | 14.899 | 6.055 | .004505 |
| 223 | 700.57 | 39037.51 | 49,729 | 11,089,567 | 14.933 | 6.064 | .004484 |
| 224 | 703.71 | 39408.23 | 50,176 | 11,239,424 | 14.966 | 6.073 | .004464 |
| 225 | 706.86 | 39760.87 | 50,625 | 11,390,625 | 15.000 | 6.082 | .004444 |

NUMBERS, DIAMETERS AND AREAS, ETC.—(*Cont.*)

| Number or Diameter | Circumference | Circular Area | Square | Cube | Square Root | Cube Root | Reciprocal |
|---|---|---|---|---|---|---|---|
| 226 | 710.00 | 40115.09 | 51,076 | 11,543,176 | 15.033 | 6.091 | .004425 |
| 227 | 713.14 | 40470.87 | 51,529 | 11,697,083 | 15.066 | 6.100 | .004405 |
| 228 | 716.28 | 40828.23 | 51,984 | 11,852,352 | 15.099 | 6.109 | .004386 |
| 229 | 719.42 | 41187.16 | 52,441 | 12,008,989 | 15.132 | 6.118 | .004367 |
| 230 | 722.56 | 41547.66 | 52,900 | 12,167,000 | 15.165 | 6.126 | .004348 |
| 231 | 725.70 | 41909.72 | 53,361 | 12,326,391 | 15.198 | 6.135 | .004329 |
| 232 | 728.85 | 42273.36 | 53,824 | 12,487,168 | 15.231 | 6.144 | .004310 |
| 233 | 731.99 | 42638.58 | 54,289 | 12,649,337 | 15.264 | 6.153 | .004292 |
| 234 | 735.13 | 43005.36 | 54,756 | 12,812,904 | 15.297 | 6.162 | .004274 |
| 235 | 738.27 | 43373.71 | 55,225 | 12,977,875 | 15.329 | 6.171 | .004255 |
| 236 | 741.41 | 43743.63 | 55,696 | 13,144,256 | 15.362 | 6.179 | .004237 |
| 237 | 744.55 | 44115.11 | 56,169 | 13,312,053 | 15.394 | 6.188 | .004219 |
| 238 | 747.68 | 44488.19 | 56,644 | 13,481,272 | 15.427 | 6.197 | .004202 |
| 239 | 750.88 | 44862.83 | 57,121 | 13,651,919 | 15.459 | 6.205 | .004184 |
| 240 | 753.98 | 45239.04 | 57,600 | 13,824,000 | 15.491 | 6.214 | .004167 |
| 241 | 757.12 | 45616.81 | 58,081 | 13,997,521 | 15.524 | 6.223 | .004149 |
| 242 | 760.26 | 45996.16 | 58,564 | 14,172,488 | 15.556 | 6.231 | .004132 |
| 243 | 763.40 | 46377.08 | 59,049 | 14,348,907 | 15.588 | 6.240 | .004115 |
| 244 | 766.52 | 46759.57 | 59,536 | 14,526,784 | 15.620 | 6.248 | .004098 |
| 245 | 769.92 | 47143.63 | 60,025 | 14,706,125 | 15.652 | 6.257 | .004082 |
| 246 | 772.83 | 47529.26 | 60,516 | 14,886,936 | 15.684 | 6.265 | .004065 |
| 247 | 775.97 | 47916.46 | 61,009 | 15,069,223 | 15.716 | 6.274 | .004049 |
| 248 | 779.11 | 48305.24 | 61,504 | 15,252,992 | 15.748 | 6.282 | .004032 |
| 249 | 782.25 | 48695.58 | 62,001 | 15,438,249 | 15.779 | 6.291 | .004016 |
| 250 | 785.40 | 49087.50 | 62,500 | 15,625,000 | 15.811 | 6.299 | .004000 |
| 251 | 788.54 | 49480.98 | 63,001 | 15,813,251 | 15.842 | 6.307 | .003984 |
| 252 | 791.68 | 49876.04 | 63,504 | 16,003,008 | 15.874 | 6.316 | .003968 |
| 253 | 794.82 | 50272.66 | 64,009 | 16,194,277 | 15.905 | 6.324 | .003953 |
| 254 | 797.96 | 50670.86 | 64,516 | 16,387,064 | 15.937 | 6.333 | .003937 |
| 255 | 801.10 | 51070.63 | 65,025 | 16,581,375 | 15.968 | 6.341 | .003922 |
| 256 | 804.24 | 51471.96 | 65,536 | 16,777,216 | 16.000 | 6.349 | .003906 |
| 257 | 807.39 | 51874.88 | 66,049 | 16,974,593 | 16.031 | 6.357 | .003891 |
| 258 | 810.53 | 52279.36 | 66,564 | 17,173,512 | 16.062 | 6.366 | .003876 |
| 259 | 813.67 | 52685.41 | 67,081 | 17,373,979 | 16.093 | 6.374 | .003861 |
| 260 | 816.81 | 53093.04 | 67,600 | 17,576,000 | 16.124 | 6.382 | .003846 |
| 261 | 819.95 | 53502.23 | 68,121 | 17,779,581 | 16.155 | 6.390 | .003831 |
| 262 | 823.09 | 53912.99 | 68,644 | 17,984,728 | 16.186 | 6.398 | .003817 |
| 263 | 826.24 | 54325.33 | 69,169 | 18,191,447 | 16.217 | 6.406 | .003802 |
| 264 | 829.38 | 54739.23 | 69,696 | 18,399,744 | 16.248 | 6.415 | .003788 |
| 265 | 832.52 | 55154.71 | 70,225 | 18,609,625 | 16.278 | 6.423 | .003774 |
| 266 | 835.66 | 55571.76 | 70,756 | 18,821,096 | 16.309 | 6.431 | .003759 |
| 267 | 838.80 | 55990.38 | 71,289 | 19,034,163 | 16.340 | 6.439 | .003745 |
| 268 | 841.94 | 56410.56 | 71,824 | 19,248,832 | 16.370 | 6.447 | .003731 |
| 269 | 845.09 | 56832.32 | 72,361 | 19,465,109 | 16.401 | 6.455 | .003717 |
| 270 | 848.23 | 57255.66 | 72,900 | 19,683,000 | 16.431 | 6.463 | .003704 |

NUMBERS, DIAMETERS AND AREAS, ETC.—(*Cont.*)

| Number or Diameter | Circumference | Circular Area | Square | Cube | Square Root | Cube Root | Reciprocal |
|---|---|---|---|---|---|---|---|
| 271 | 851.37 | 57680.56 | 73,441 | 19,902,511 | 16.462 | 6.471 | .003690 |
| 272 | 854.51 | 58107.03 | 73,984 | 20,123,648 | 16.492 | 6.479 | .003676 |
| 273 | 857.65 | 58535.07 | 74,529 | 20,346,417 | 16.522 | 6.487 | .003663 |
| 274 | 860.79 | 58964.69 | 75,076 | 20,570,824 | 16.552 | 6.495 | .003650 |
| 275 | 863.94 | 59393.87 | 75,625 | 20,796,875 | 16.583 | 6.502 | .003636 |
| 276 | 867.08 | 59828.63 | 76,176 | 21,024,576 | 16.613 | 6.510 | .003623 |
| 277 | 870.22 | 60262.95 | 76,729 | 21,253,933 | 16.643 | 6.518 | .003610 |
| 278 | 873.36 | 60698.85 | 77,284 | 21,484,952 | 16.673 | 6.526 | .003597 |
| 279 | 876.50 | 61136.32 | 77,841 | 21,717,639 | 16.703 | 6.534 | .003584 |
| 280 | 879.64 | 61573.36 | 78,400 | 21,952,000 | 16.733 | 6.542 | .003571 |
| 281 | 882.78 | 62015.96 | 78,961 | 22,188,041 | 16.763 | 6.549 | .003559 |
| 282 | 885.93 | 62458.14 | 79,524 | 22,425,768 | 16.792 | 6.557 | .003546 |
| 283 | 889.07 | 62901.90 | 80,089 | 22,665,187 | 16.822 | 6.565 | .003534 |
| 284 | 892.21 | 63347.22 | 80,656 | 22,906,304 | 16.852 | 6.573 | .003522 |
| 285 | 895.35 | 63794.11 | 81,225 | 23,149,125 | 16.881 | 6.580 | .003509 |
| 286 | 898.49 | 64242.57 | 81,796 | 23,393,656 | 16.911 | 6.588 | .003497 |
| 287 | 901.63 | 64692.61 | 82,369 | 23,639,903 | 16.941 | 6.596 | .003484 |
| 288 | 904.78 | 65144.21 | 82,944 | 23,887,872 | 16.970 | 6.603 | .003472 |
| 289 | 907.92 | 65597.39 | 83,521 | 24,137,569 | 17.000 | 6.611 | .003460 |
| 290 | 911.06 | 66052.14 | 84,100 | 24,389,000 | 17.029 | 6.619 | .003448 |
| 291 | 914.20 | 66508.45 | 84,681 | 24,642,171 | 17.059 | 6.627 | .003436 |
| 292 | 917.34 | 66966.34 | 85,264 | 24,897,088 | 17.088 | 6.634 | .003425 |
| 293 | 920.48 | 67425.80 | 85,849 | 25,153,757 | 17.117 | 6.642 | .003413 |
| 294 | 923.63 | 67886.83 | 86,436 | 25,412,184 | 17.146 | 6.649 | .003401 |
| 295 | 926.77 | 68349.43 | 87,025 | 25,672,375 | 17.176 | 6.657 | .003390 |
| 296 | 929.91 | 68813.60 | 87,616 | 25,934,336 | 17.205 | 6.664 | .003378 |
| 297 | 933.05 | 69279.34 | 88,209 | 26,198,073 | 17.234 | 6.672 | .003367 |
| 298 | 936.19 | 69746.66 | 88,804 | 26,463,592 | 17.263 | 6.679 | .003356 |
| 299 | 939.33 | 70215.54 | 89,401 | 26,730,899 | 17.292 | 6.687 | .003344 |
| 300 | 942.48 | 70686.00 | 90,000 | 27,000,000 | 17.320 | 6.694 | .003333 |
| 301 | 945.62 | 71158.02 | 90,601 | 27,270,901 | 17.349 | 6.702 | .003322 |
| 302 | 948.76 | 71631.62 | 91,204 | 27,543,608 | 17.378 | 6.709 | .003311 |
| 303 | 951.90 | 72106.78 | 91,809 | 27,818,127 | 17.407 | 6.717 | .003301 |
| 304 | 955.04 | 72583.52 | 92,416 | 28,094,464 | 17.436 | 6.724 | .003289 |
| 305 | 958.18 | 73061.83 | 93,025 | 28,372,625 | 17.464 | 6.731 | .003279 |
| 306 | 961.32 | 73541.71 | 93,636 | 28,652,616 | 17.493 | 6.739 | .003268 |
| 307 | 964.47 | 74023.16 | 94,249 | 28,934,443 | 17.521 | 6.746 | .003257 |
| 308 | 967.61 | 74506.18 | 94,864 | 29,218,112 | 17.549 | 6.753 | .003247 |
| 309 | 970.75 | 74990.77 | 95,481 | 29,503,629 | 17.578 | 6.761 | .003236 |
| 310 | 973.89 | 75476.94 | 96,100 | 29,791,000 | 17.607 | 6.768 | .003226 |
| 311 | 977.03 | 75964.67 | 96,721 | 30,080,231 | 17.635 | 6.775 | .003215 |
| 312 | 980.17 | 76453.93 | 97,344 | 30,371,328 | 17.663 | 6.782 | .003205 |
| 313 | 983.32 | 76944.85 | 97,969 | 30,664,297 | 17.692 | 6.789 | .003195 |
| 314 | 986.45 | 77437.29 | 98,596 | 30,959,144 | 17.720 | 6.797 | .003185 |
| 315 | 989.60 | 77931.31 | 99,225 | 31,255,875 | 17.748 | 6.804 | .003175 |

NUMBERS, DIAMETERS AND AREAS, ETC.—(*Cont.*)

| Number or Diameter | Circumference | Circular Area | Square | Cube | Square Root | Cube Root | Reciprocal |
|---|---|---|---|---|---|---|---|
| 316 | 992.74 | 78426.89 | 99,856 | 31,554,496 | 17.776 | 6.811 | .003165 |
| 317 | 995.88 | 78924.06 | 100,489 | 31,855,013 | 17.804 | 6.818 | .003155 |
| 318 | 999.02 | 79422.78 | 101,124 | 32,157,432 | 17.832 | 6.826 | .003145 |
| 319 | 1002.17 | 79923.08 | 101,761 | 32,461,759 | 17.860 | 6.833 | .003135 |
| 320 | 1005.31 | 80424.96 | 102,400 | 32,768,000 | 17.888 | 6.839 | .003125 |
| 321 | 1008.45 | 80928.40 | 103,041 | 33,076,161 | 17.916 | 6.847 | .003115 |
| 322 | 1011.59 | 81433.41 | 103,684 | 33,386,248 | 17.944 | 6.854 | .003106 |
| 323 | 1014.73 | 81939.99 | 104,329 | 33,698,267 | 17.972 | 6.861 | .003096 |
| 324 | 1017.47 | 82448.15 | 104,976 | 34,012,224 | 18.000 | 6.868 | .003086 |
| 325 | 1021.02 | 82957.87 | 105,625 | 34,328,125 | 18.028 | 6.875 | .003077 |
| 326 | 1024.16 | 83469.17 | 106,276 | 34,645,976 | 18.055 | 6.882 | .003067 |
| 327 | 1027.30 | 83982.60 | 106,929 | 34,965,783 | 18.083 | 6.889 | .003058 |
| 328 | 1030.44 | 84496.47 | 107,584 | 35,287,552 | 18.111 | 6.896 | .003049 |
| 329 | 1033.58 | 85012.48 | 108,241 | 35,611,289 | 18.138 | 6.903 | .003040 |
| 330 | 1036.72 | 85530.06 | 108,900 | 35,937,000 | 18.166 | 6.910 | .003030 |
| 331 | 1039.86 | 86049.20 | 109,561 | 36,264,691 | 18.193 | 6.917 | .003021 |
| 332 | 1043.01 | 86569.92 | 110,224 | 36,594,368 | 18.221 | 6.924 | .003012 |
| 333 | 1046.15 | 87092.22 | 110,889 | 36,926,037 | 18.248 | 6.931 | .003003 |
| 334 | 1049.29 | 87616.08 | 111,556 | 37,259,704 | 18.276 | 6.938 | .002994 |
| 335 | 1052.43 | 88141.51 | 112,225 | 37,595,375 | 18.303 | 6.945 | .002985 |
| 336 | 1055.57 | 88668.51 | 112,896 | 37,933,056 | 18.330 | 6.952 | .002976 |
| 337 | 1058.71 | 89197.09 | 113,569 | 38,272,753 | 18.357 | 6.959 | .002967 |
| 338 | 1061.86 | 89727.23 | 114,244 | 38,614,472 | 18.385 | 6.966 | .002959 |
| 339 | 1065.02 | 90258.95 | 114,921 | 38,958,219 | 18.412 | 6.973 | .002950 |
| 340 | 1068.14 | 90792.24 | 115,600 | 39,304,000 | 18.439 | 6.979 | .002941 |
| 341 | 1071.28 | 91327.09 | 116,281 | 39,651,821 | 18.466 | 6.986 | .002933 |
| 342 | 1074.27 | 91863.52 | 116,964 | 40,001,688 | 18.493 | 6.993 | .002924 |
| 343 | 1077.56 | 92401.15 | 117,649 | 40,353,607 | 18.520 | 7.000 | .002915 |
| 344 | 1080.71 | 92941.09 | 118,336 | 40,707,584 | 18.547 | 7.007 | .002907 |
| 345 | 1083.85 | 93482.23 | 119,025 | 41,063,625 | 18.574 | 7.014 | .002899 |
| 346 | 1086.99 | 94024.94 | 119,716 | 41,421,736 | 18.601 | 7.020 | .002890 |
| 347 | 1090.35 | 94569.22 | 120,409 | 41,781,923 | 18.628 | 7.027 | .002882 |
| 348 | 1093.07 | 95115.08 | 121,104 | 42,144,192 | 18.655 | 7.034 | .002874 |
| 349 | 1096.41 | 95662.50 | 121,801 | 42,508,549 | 18.681 | 7.040 | .002865 |
| 350 | 1099.56 | 96211.50 | 122,500 | 42,875,000 | 18.708 | 7.047 | .002857 |
| 351 | 1102.70 | 96762.06 | 123,201 | 43,243,551 | 18.735 | 7.054 | .002849 |
| 352 | 1105.84 | 97314.20 | 123,904 | 43,614,208 | 18.762 | 7.061 | .002841 |
| 353 | 1108.98 | 97867.90 | 124,609 | 43,986,977 | 18.788 | 7.067 | .002833 |
| 354 | 1112.62 | 98423.18 | 125,316 | 44,361,864 | 18.815 | 7.074 | .002825 |
| 355 | 1115.26 | 98980.03 | 126,025 | 44,738,875 | 18.842 | 7.081 | .002817 |
| 356 | 1118.40 | 99538.45 | 126,736 | 45,118,016 | 18.868 | 7.087 | .002809 |
| 357 | 1121.55 | 100098.43 | 127,449 | 45,449,293 | 18.894 | 7.094 | .002801 |
| 358 | 1124.69 | 100660.00 | 128,164 | 45,882,712 | 18.921 | 7.101 | .002793 |
| 359 | 1127.83 | 101223.13 | 128,881 | 46,268,279 | 18.947 | 7.107 | .002786 |
| 360 | 1130.97 | 101787.84 | 129,600 | 46,656,000 | 18.974 | 7.114 | .002778 |

NUMBERS, DIAMETERS AND AREAS, ETC.—(*Cont.*)

| Number or Diameter | Circumference | Circular Area | Square | Cube | Square Root | Cube Root | Reciprocal |
|---|---|---|---|---|---|---|---|
| 361 | 1134.11 | 102354.11 | 130,321 | 47,045,881 | 19.000 | 7.120 | .002770 |
| 362 | 1137.25 | 102921.95 | 131,044 | 47,437,928 | 19.026 | 7.127 | .002762 |
| 363 | 1140.40 | 103491.31 | 131,769 | 47,832,147 | 19.052 | 7.133 | .002755 |
| 364 | 1143.54 | 104062.35 | 132,496 | 48,228,544 | 19.079 | 7.140 | .002747 |
| 365 | 1146.68 | 104634.91 | 133,225 | 48,627,125 | 19.105 | 7.146 | .002740 |
| 366 | 1149.82 | 105209.04 | 133,956 | 49,027,896 | 19.131 | 7.153 | .002732 |
| 367 | 1152.96 | 105784.74 | 134,689 | 49,430,863 | 19.157 | 7.159 | .002725 |
| 368 | 1156.10 | 106362.00 | 135,424 | 49,836,032 | 19.183 | 7.166 | .002717 |
| 369 | 1159.25 | 106940.84 | 136,161 | 50,243,409 | 19.209 | 7.172 | .002710 |
| 370 | 1162.39 | 107521.26 | 136,900 | 50,653,000 | 19.235 | 7.179 | .002703 |
| 371 | 1165.53 | 108103.22 | 137,641 | 51,064,811 | 19.261 | 7.185 | .002695 |
| 372 | 1168.67 | 108686.79 | 138,384 | 51,478,848 | 19.287 | 7.192 | .002688 |
| 373 | 1171.81 | 109271.91 | 139,129 | 51,895,117 | 19.313 | 7.198 | .002681 |
| 374 | 1174.95 | 109858.62 | 139,876 | 52,313,624 | 19.339 | 7.205 | .002674 |
| 375 | 1178.10 | 110446.87 | 140,625 | 52,734,375 | 19.365 | 7.211 | .002667 |
| 376 | 1181.24 | 111036.71 | 141,376 | 53,157,376 | 19.391 | 7.218 | .002660 |
| 377 | 1184.38 | 111628.11 | 142,129 | 53,582,633 | 19.416 | 7.224 | .002653 |
| 378 | 1187.52 | 112221.09 | 142,884 | 54,010,152 | 19.442 | 7.230 | .002646 |
| 379 | 1190.66 | 112815.64 | 143,641 | 54,439,939 | 19.468 | 7.237 | .002639 |
| 380 | 1193.80 | 113411.76 | 144,400 | 54,872,000 | 19.493 | 7.243 | .002632 |
| 381 | 1196.94 | 114009.46 | 145,161 | 55,306,341 | 19.519 | 7.249 | .002625 |
| 382 | 1200.09 | 114608.70 | 145,924 | 55,742,968 | 19.545 | 7.256 | .002618 |
| 383 | 1203.23 | 115209.54 | 146,689 | 56,181,887 | 19.570 | 7.262 | .002611 |
| 384 | 1206.37 | 115811.94 | 147,456 | 56,623,104 | 19.596 | 7.268 | .002604 |
| 385 | 1209.51 | 116415.91 | 148,225 | 57,066,625 | 19.621 | 7.275 | .002597 |
| 386 | 1212.65 | 117021.45 | 148,996 | 57,512,456 | 19.647 | 7.281 | .002591 |
| 387 | 1215.79 | 117628.57 | 149,769 | 57,960,603 | 19.672 | 7.287 | .002584 |
| 388 | 1218.94 | 118237.25 | 150,544 | 58,411,072 | 19.698 | 7.294 | .002577 |
| 389 | 1222.08 | 118846.51 | 151,321 | 58,863,869 | 19.723 | 7.299 | .002571 |
| 390 | 1225.22 | 119453.94 | 152,100 | 59,319,000 | 19.748 | 7.306 | .002564 |
| 391 | 1228.36 | 120072.73 | 152,881 | 59,776,471 | 19.774 | 7.312 | .002558 |
| 392 | 1231.50 | 120687.70 | 153,664 | 60,236,288 | 19.799 | 7.319 | .002551 |
| 393 | 1234.64 | 121304.24 | 154,449 | 60,698,457 | 19.824 | 7.325 | .002545 |
| 394 | 1237.79 | 121922.43 | 155,236 | 61,162,984 | 19.849 | 7.331 | .002538 |
| 395 | 1240.93 | 122542.03 | 156,025 | 61,629,875 | 19.875 | 7.337 | .002532 |
| 396 | 1244.07 | 123163.28 | 156,816 | 62,099,136 | 19.899 | 7.343 | .002525 |
| 397 | 1247.21 | 123786.10 | 157,609 | 62,570,773 | 19.925 | 7.349 | .002519 |
| 398 | 1250.35 | 124412.10 | 158,404 | 63,044,792 | 19.949 | 7.356 | .002513 |
| 399 | 1253.49 | 125036.46 | 159,201 | 63,521,199 | 19.975 | 7.362 | .002506 |
| 400 | 1256.64 | 125664.00 | 160,000 | 64,000,000 | 20.000 | 7.368 | .002500 |
| 401 | 1259.78 | 126293.10 | 160,801 | 64,481,201 | 20.025 | 7.374 | .002494 |
| 402 | 1262.92 | 126923.88 | 161,604 | 64,964,808 | 20.049 | 7.380 | .002488 |
| 403 | 1266.06 | 127556.02 | 162,409 | 65,450,827 | 20.075 | 7.386 | .002481 |
| 404 | 1269.20 | 128189.84 | 163,216 | 65,939,264 | 20.099 | 7.392 | .002475 |
| 405 | 1272.34 | 128825.23 | 164,025 | 66,430,125 | 20.125 | 7.399 | .002469 |

NUMBERS, DIAMETERS AND AREAS, ETC.—(*Cont.*)

| Number or Diameter | Circumference | Circular Area | Square | Cube | Square Root | Cube Root | Reciprocal |
|---|---|---|---|---|---|---|---|
| 406 | 1275.48 | 129462.19 | 164,836 | 66,923,416 | 20.149 | 7.405 | .002463 |
| 407 | 1278.63 | 130100.71 | 165,649 | 67,419,143 | 20.174 | 7.411 | .002457 |
| 408 | 1281.77 | 130740.82 | 166,464 | 67,911,312 | 20.199 | 7.417 | .002451 |
| 409 | 1284.91 | 131382.49 | 167,281 | 68,417,929 | 20.224 | 7.422 | .002445 |
| 410 | 1288.05 | 132025.74 | 168,100 | 68,921,000 | 20.248 | 7.429 | .002439 |
| 411 | 1291.19 | 132670.55 | 168,921 | 69,426,531 | 20.273 | 7.434 | .002433 |
| 412 | 1294.32 | 133316.93 | 169,744 | 69,934,528 | 20.298 | 7.441 | .002427 |
| 413 | 1297.48 | 133964.89 | 170,569 | 70,444,997 | 20.322 | 7.447 | .002421 |
| 414 | 1300.62 | 134614.41 | 171,396 | 70,957,944 | 20.347 | 7.453 | .002415 |
| 415 | 1303.76 | 135265.51 | 172,225 | 71,473,375 | 20.371 | 7.459 | .002410 |
| 416 | 1306.90 | 135918.18 | 173,056 | 71,991,296 | 20.396 | 7.465 | .002407 |
| 417 | 1310.04 | 136572.42 | 173,889 | 72,511,713 | 20.421 | 7.471 | .002398 |
| 418 | 1313.18 | 137228.22 | 174,724 | 73,034,632 | 20.445 | 7.477 | .002392 |
| 419 | 1316.32 | 137885.69 | 175,561 | 73,560,059 | 20.469 | 7.483 | .002387 |
| 420 | 1319.47 | 138544.56 | 176,400 | 74,088,000 | 20.494 | 7.489 | .002381 |
| 421 | 1322.61 | 139205.08 | 177,241 | 74,618,461 | 20.518 | 7.495 | .002375 |
| 422 | 1325.75 | 139867.17 | 178,084 | 75,151,448 | 20.543 | 7.501 | .002370 |
| 423 | 1328.89 | 140530.83 | 178,929 | 75,666,967 | 20.567 | 7.507 | .002364 |
| 424 | 1332.03 | 141196.07 | 179,776 | 76,225,024 | 20.591 | 7.513 | .002358 |
| 425 | 1335.18 | 141862.87 | 180,625 | 76,765,625 | 20.615 | 7.518 | .002353 |
| 426 | 1338.32 | 142531.25 | 181,476 | 77,308,776 | 20.639 | 7.524 | .002347 |
| 427 | 1341.46 | 143201.19 | 182,329 | 77,854,483 | 20.664 | 7.530 | .002342 |
| 428 | 1344.60 | 143872.71 | 183,184 | 78,402,752 | 20.688 | 7.536 | .002336 |
| 429 | 1347.74 | 144545.80 | 184,041 | 78,953,589 | 20.712 | 7.542 | .002331 |
| 430 | 1350.88 | 145220.46 | 184,900 | 79,507,000 | 20.736 | 7.548 | .002326 |
| 431 | 1354.02 | 145696.68 | 185,761 | 80,062,991 | 20.760 | 7.554 | .002320 |
| 432 | 1357.17 | 146574.48 | 186,624 | 80,621,568 | 20.785 | 7.559 | .002315 |
| 433 | 1360.33 | 147253.85 | 187,489 | 81,182,737 | 20.809 | 7.565 | .002309 |
| 434 | 1363.45 | 147934.80 | 188,356 | 81,746,504 | 20.833 | 7.571 | .002304 |
| 435 | 1366.59 | 148617.31 | 189,225 | 82,312,875 | 20.857 | 7.577 | .002299 |
| 436 | 1369.73 | 149301.39 | 190,096 | 82,881,856 | 20.881 | 7.583 | .002294 |
| 437 | 1372.87 | 149987.05 | 190,969 | 83,453,453 | 20.904 | 7.588 | .002288 |
| 438 | 1376.02 | 150674.27 | 191,844 | 84,027,672 | 20.928 | 7.594 | .002283 |
| 439 | 1379.16 | 151362.87 | 192,721 | 84,604,519 | 20.952 | 7.600 | .002278 |
| 440 | 1382.30 | 152053.44 | 193,600 | 85,184,000 | 20.976 | 7.606 | .002273 |
| 441 | 1385.44 | 152745.37 | 194,481 | 85,766,121 | 21.000 | 7.612 | .002268 |
| 442 | 1388.58 | 153438.88 | 195,364 | 86,350,388 | 21.024 | 7.617 | .002262 |
| 443 | 1391.72 | 154133.96 | 196,249 | 86,938,307 | 21.047 | 7.623 | .002257 |
| 444 | 1394.87 | 154830.61 | 197,136 | 87,528,384 | 21.071 | 7.629 | .002252 |
| 445 | 1398.01 | 155528.83 | 198,025 | 88,121,125 | 21.095 | 7.635 | .002247 |
| 446 | 1401.15 | 156228.62 | 198,916 | 88,716,536 | 21.119 | 7.640 | .002242 |
| 447 | 1404.29 | 156929.98 | 199,809 | 89,314,623 | 21.142 | 7.646 | .002237 |
| 448 | 1407.43 | 157632.92 | 200,704 | 89,915,392 | 21.166 | 7.652 | .002232 |
| 449 | 1410.57 | 158337.42 | 201,601 | 90,518,849 | 21.189 | 7.657 | .002227 |
| 450 | 1413.72 | 159043.50 | 202,500 | 91,125,000 | 21.213 | 7.663 | .002222 |

NUMBERS, DIAMETERS AND AREAS, ETC.—(*Cont.*)

| Number or Diameter | Circum-ference | Circular Area | Square | Cube | Square Root | Cube Root | Reciprocal |
|---|---|---|---|---|---|---|---|
| 451 | 1416.86 | 159751.14 | 203,401 | 91,733,851 | 21.237 | 7.669 | .002217 |
| 452 | 1420.00 | 160460.36 | 204,304 | 92,345,408 | 21.260 | 7.674 | .002212 |
| 453 | 1423.14 | 161171.14 | 205,209 | 92,959,677 | 21.284 | 7.680 | .002208 |
| 454 | 1426.28 | 161883.50 | 206,106 | 93,576,664 | 21.307 | 7.686 | .002203 |
| 455 | 1429.42 | 162597.43 | 207,025 | 94,196,375 | 21.331 | 7.691 | .002198 |
| 456 | 1432.56 | 163312.93 | 207,936 | 94,818,816 | 21.354 | 7.697 | .002193 |
| 457 | 1435.71 | 164030.20 | 208,849 | 95,443,993 | 21.377 | 7.703 | .002188 |
| 458 | 1438.85 | 164748.64 | 209,764 | 96,071,912 | 21.401 | 7.708 | .002183 |
| 459 | 1441.99 | 165468.85 | 210,681 | 96,702,579 | 21.424 | 7.714 | .002179 |
| 460 | 1445.13 | 166190.64 | 211,600 | 97,336,000 | 21.447 | 7.719 | .002174 |
| 461 | 1448.27 | 166913.99 | 212,521 | 97,972,181 | 21.471 | 7.725 | .002169 |
| 462 | 1451.41 | 167638.91 | 213,444 | 98,611,128 | 21.494 | 7.731 | .002165 |
| 463 | 1454.56 | 168365.41 | 214,369 | 99,252,847 | 21.517 | 7.736 | .002160 |
| 464 | 1457.70 | 169093.47 | 215,296 | 99,897,345 | 21.541 | 7.742 | .002155 |
| 465 | 1460.84 | 169823.11 | 216,225 | 100,544,625 | 21.564 | 7.747 | .002151 |
| 466 | 1463.98 | 170554.32 | 217,156 | 101,194,696 | 21.587 | 7.753 | .002146 |
| 467 | 1467.12 | 171287.10 | 218,089 | 101,847,563 | 21.610 | 7.758 | .002141 |
| 468 | 1470.26 | 172021.44 | 219,024 | 102,503,232 | 21.633 | 7.764 | .002137 |
| 469 | 1473.41 | 172757.36 | 219,961 | 103,161,709 | 21.656 | 7.769 | .002132 |
| 470 | 1476.55 | 173494.86 | 220,900 | 103,823,000 | 21.679 | 7.775 | .002128 |
| 471 | 1479.69 | 174233.92 | 221,841 | 104,487,111 | 21.702 | 7.780 | .002123 |
| 472 | 1482.83 | 174974.55 | 222,784 | 105,154,048 | 21.725 | 7.786 | .002119 |
| 473 | 1485.97 | 175716.75 | 223,729 | 105,823,817 | 21.749 | 7.791 | .002114 |
| 474 | 1489.11 | 176460.45 | 224,676 | 106,496,424 | 21.771 | 7.797 | .002110 |
| 475 | 1492.26 | 177205.87 | 225,625 | 107,171,875 | 21.794 | 7.802 | .002105 |
| 476 | 1495.36 | 177952.79 | 226,576 | 107,850,176 | 21.817 | 7.808 | .002101 |
| 477 | 1498.54 | 178701.27 | 227,529 | 108,531,333 | 21.840 | 7.813 | .002096 |
| 478 | 1501.68 | 179451.33 | 228,484 | 109,215,352 | 21.863 | 7.819 | .002092 |
| 479 | 1504.82 | 180202.96 | 229,441 | 109,902,239 | 21.886 | 7.824 | .002088 |
| 480 | 1507.96 | 180956.16 | 230,400 | 110,592,000 | 21.909 | 7.830 | .002083 |
| 481 | 1511.10 | 181712.92 | 231,361 | 111,284,641 | 21.932 | 7.835 | .002079 |
| 482 | 1514.25 | 182467.26 | 232,324 | 111,980,168 | 21.954 | 7.840 | .002075 |
| 483 | 1517.39 | 183225.18 | 233,289 | 112,678,587 | 21.977 | 7.846 | .002070 |
| 484 | 1520.53 | 183984.66 | 234,256 | 113,379,904 | 22.000 | 7.851 | .002066 |
| 485 | 1523.67 | 184745.71 | 235,225 | 114,084,125 | 22.023 | 7.857 | .002062 |
| 486 | 1526.81 | 185508.33 | 236,196 | 114,791,256 | 22.045 | 7.862 | .002058 |
| 487 | 1529.95 | 186272.53 | 237,169 | 115,501,303 | 22.069 | 7.868 | .002053 |
| 488 | 1533.90 | 187038.29 | 238,144 | 116,214,272 | 22.091 | 7.873 | .002049 |
| 489 | 1536.24 | 187805.63 | 239,121 | 116,936,169 | 22.113 | 7.878 | .002045 |
| 490 | 1539.38 | 188574.54 | 240,100 | 117,649,000 | 22.136 | 7.884 | .002041 |
| 491 | 1542.52 | 189345.01 | 241,081 | 118,370,771 | 22.158 | 7.889 | .002037 |
| 492 | 1545.66 | 190117.06 | 242,064 | 119,095,488 | 22.181 | 7.894 | .002033 |
| 493 | 1548.80 | 190890.68 | 243,049 | 119,823,157 | 22.204 | 7.899 | .002028 |
| 494 | 1551.95 | 191665.87 | 244,036 | 120,553,784 | 22.226 | 7.905 | .002024 |
| 495 | 1555.09 | 192442.63 | 245,025 | 121,287,375 | 22.248 | 7.910 | .002020 |

NUMBERS, DIAMETERS AND AREAS, ETC.—(*Cont.*)

| Number or Diameter | Circum-ference | Circular Area | Square | Cube | Square Root | Cube Root | Reciprocal |
|---|---|---|---|---|---|---|---|
| 496 | 1558.23 | 193220.96 | 246,016 | 122,023,936 | 22.271 | 7.915 | .002016 |
| 497 | 1561.37 | 194000.86 | 247,009 | 122,763,473 | 22.293 | 7.921 | .002012 |
| 498 | 1564.51 | 194782.34 | 248,004 | 123,505,992 | 22.316 | 7.926 | .002008 |
| 499 | 1567.55 | 195565.38 | 249,001 | 124,251,499 | 22.338 | 7.932 | .002004 |
| 500 | 1570.80 | 196350.00 | 250,000 | 125,000,000 | 22.361 | 7.937 | .002000 |
| 501 | 1573.94 | 197136.18 | 251,001 | 125,751,501 | 22.383 | 7.942 | .001996 |
| 502 | 1577.08 | 197923.94 | 252,004 | 126,506,008 | 22.405 | 7.947 | .001992 |
| 503 | 1580.22 | 198713.26 | 253,009 | 127,263,527 | 22.428 | 7.953 | .001988 |
| 504 | 1583.36 | 199504.16 | 254,016 | 128,024,864 | 22.449 | 7.958 | .001984 |
| 505 | 1586.50 | 200296.63 | 255,025 | 128,787,625 | 22.472 | 7.963 | .001980 |
| 506 | 1589.64 | 201090.67 | 256,036 | 129,554,216 | 22.494 | 7.969 | .001976 |
| 507 | 1592.79 | 201886.28 | 257,049 | 130,323,843 | 22.517 | 7.974 | .001972 |
| 508 | 1595.93 | 202683.46 | 258,064 | 131,096,512 | 22.539 | 7.979 | .001969 |
| 509 | 1599.07 | 203487.70 | 259,081 | 131,872,229 | 22.561 | 7.984 | .001965 |
| 510 | 1602.21 | 204282.54 | 260,100 | 132,651,000 | 22.583 | 7.989 | .001961 |
| 511 | 1605.35 | 205084.43 | 261,121 | 133,432,831 | 22.605 | 7.995 | .001957 |
| 512 | 1608.49 | 205887.84 | 262,144 | 134,217,728 | 22.627 | 8.000 | .001953 |
| 513 | 1611.64 | 206692.93 | 263,169 | 135,005,697 | 22.649 | 8.005 | .001949 |
| 514 | 1614.78 | 207499.53 | 264,196 | 135,796,744 | 22.671 | 8.010 | .001946 |
| 515 | 1617.92 | 208307.71 | 265,225 | 136,590,875 | 22.694 | 8.016 | .001942 |
| 516 | 1621.06 | 209117.46 | 266,256 | 137,388,096 | 22.716 | 8.021 | .001938 |
| 517 | 1624.20 | 209928.78 | 267,289 | 138,188,413 | 22.738 | 8.026 | .001934 |
| 518 | 1627.34 | 210741.66 | 268,324 | 138,991,832 | 22.759 | 8.031 | .001931 |
| 519 | 1630.49 | 211556.12 | 269,361 | 139,798,359 | 22.782 | 8.036 | .001927 |
| 520 | 1633.63 | 212372.16 | 270,400 | 140,608,000 | 22.803 | 8.041 | .001923 |
| 521 | 1636.77 | 213189.76 | 271,441 | 141,420,761 | 22.825 | 8.047 | .001919 |
| 522 | 1639.93 | 214008.93 | 272,484 | 142,236,648 | 22.847 | 8.052 | .001916 |
| 523 | 1643.05 | 214829.67 | 273,529 | 143,055,667 | 22.869 | 8.057 | .001912 |
| 524 | 1646.19 | 215651.99 | 274,576 | 143,877,824 | 22.891 | 8.062 | .001908 |
| 525 | 1649.34 | 216475.87 | 275,624 | 144,703,125 | 22.913 | 8.067 | .001905 |
| 526 | 1652.48 | 217301.33 | 276,676 | 145,531,576 | 22.935 | 8.072 | .001901 |
| 527 | 1655.62 | 218128.35 | 277,729 | 146,363,183 | 22.956 | 8.077 | .001898 |
| 528 | 1658.76 | 218956.95 | 278,784 | 147,197,952 | 22.978 | 8.082 | .001894 |
| 529 | 1661.90 | 219787.12 | 279,841 | 148,035,889 | 23.000 | 8.087 | .001890 |
| 530 | 1665.04 | 220618.86 | 280,900 | 148,877,000 | 23.022 | 8.093 | .001887 |
| 531 | 1668.18 | 221452.16 | 281,961 | 149,721,291 | 23.043 | 8.098 | .001883 |
| 532 | 1671.33 | 222287.04 | 283,024 | 150,568,768 | 23.065 | 8.103 | .001880 |
| 533 | 1674.47 | 223123.50 | 284,089 | 151,419,437 | 23.087 | 8.108 | .001876 |
| 534 | 1677.61 | 223961.52 | 285,156 | 152,273,304 | 23.108 | 8.113 | .001873 |
| 535 | 1680.75 | 224801.11 | 286,225 | 153,130,375 | 23.130 | 8.118 | .001869 |
| 536 | 1683.80 | 225642.27 | 287,296 | 153,990,656 | 23.152 | 8.123 | .001866 |
| 537 | 1687.04 | 226487.01 | 288,369 | 154,854,153 | 23.173 | 8.128 | .001862 |
| 538 | 1690.18 | 227329.31 | 289,444 | 155,720,872 | 23.195 | 8.133 | .001859 |
| 539 | 1693.32 | 228175.19 | 290,521 | 156,590,819 | 23.216 | 8.138 | .001855 |
| 540 | 1696.46 | 229022.64 | 291,600 | 157,464,000 | 23.238 | 8.143 | .001852 |

NUMBERS, DIAMETERS AND AREAS, ETC.—(*Cont.*)

| Number or Diameter | Circumference | Circular Area | Square | Cube | Square Root | Cube Root | Reciprocal |
|---|---|---|---|---|---|---|---|
| 541 | 1699.60 | 229871.65 | 292,681 | 158,340,421 | 23.259 | 8.148 | .001848 |
| 542 | 1702.74 | 230722.24 | 293,764 | 159,220,088 | 23.281 | 8.153 | .001845 |
| 543 | 1705.88 | 231574.40 | 294,849 | 160,103,007 | 23.302 | 8.158 | .001842 |
| 544 | 1709.03 | 232428.13 | 295,936 | 160,989,184 | 23.324 | 8.163 | .001838 |
| 545 | 1712.17 | 233283.43 | 297,025 | 161,878,625 | 23.345 | 8.168 | .001835 |
| 546 | 1715.31 | 234140.30 | 298,116 | 162,771,336 | 23.367 | 8.173 | .001832 |
| 547 | 1718.45 | 234998.74 | 299,209 | 163,667,323 | 23.388 | 8.178 | .001828 |
| 548 | 1721.59 | 235858.76 | 300,304 | 164,566,592 | 23.409 | 8.183 | .001825 |
| 549 | 1724.73 | 236720.34 | 301,401 | 165,469,149 | 23.431 | 8.188 | .001821 |
| 550 | 1727.88 | 237583.50 | 302,500 | 166,375,000 | 23.452 | 8.193 | .001818 |
| 551 | 1731.02 | 238448.22 | 303,601 | 167,284,151 | 23.473 | 8.198 | .001815 |
| 552 | 1734.16 | 239314.52 | 304,704 | 168,196,608 | 23.495 | 8.203 | .001812 |
| 553 | 1737.30 | 240182.38 | 305,809 | 169,112,377 | 23.516 | 8.208 | .001808 |
| 554 | 1740.44 | 241051.82 | 306,916 | 170,031,464 | 23.537 | 8.213 | .001805 |
| 555 | 1743.58 | 241922.83 | 308,025 | 170,953,875 | 23.558 | 8.218 | .001802 |
| 556 | 1746.72 | 242795.41 | 309,136 | 171,879,616 | 23.579 | 8.223 | .001799 |
| 557 | 1749.77 | 243669.56 | 310,249 | 172,808,693 | 23.601 | 8.228 | .001795 |
| 558 | 1753.09 | 244545.28 | 311,364 | 173,741,112 | 23.622 | 8.233 | .001792 |
| 559 | 1756.15 | 245422.57 | 312,481 | 174,676,879 | 23.643 | 8.238 | .001789 |
| 560 | 1759.29 | 246301.44 | 313,600 | 175,616,000 | 23.664 | 8.242 | .001786 |
| 561 | 1762.43 | 247181.87 | 314,721 | 176,558,481 | 23.685 | 8.247 | .001783 |
| 562 | 1765.57 | 248063.87 | 315,844 | 177,504,328 | 23.706 | 8.252 | .001779 |
| 563 | 1768.72 | 248947.45 | 316,969 | 178,453,547 | 23.728 | 8.257 | .001776 |
| 564 | 1771.86 | 249832.59 | 318,096 | 179,406,144 | 23.749 | 8.262 | .001773 |
| 565 | 1775.00 | 250719.31 | 319,225 | 180,362,125 | 23.769 | 8.267 | .001770 |
| 566 | 1778.14 | 251607.60 | 320,356 | 181,321,496 | 23.791 | 8.272 | .001767 |
| 567 | 1781.28 | 252497.36 | 321,489 | 182,284,263 | 23.812 | 8.277 | .001764 |
| 568 | 1784.42 | 253388.88 | 322,624 | 183,250,432 | 23.833 | 8.282 | .001761 |
| 569 | 1787.57 | 254281.88 | 323,761 | 184,220,009 | 23.854 | 8.286 | .001757 |
| 570 | 1790.71 | 255176.64 | 324,900 | 185,193,000 | 23.875 | 8.291 | .001754 |
| 571 | 1793.85 | 256072.60 | 326,041 | 186,169,411 | 23.896 | 8.296 | .001751 |
| 572 | 1796.99 | 256970.31 | 327,184 | 187,149,248 | 23.916 | 8.301 | .001748 |
| 573 | 1800.13 | 257869.59 | 328,329 | 188,132,517 | 23.937 | 8.306 | .001745 |
| 574 | 1803.27 | 258770.45 | 329,476 | 189,119,224 | 23.958 | 8.311 | .001742 |
| 575 | 1806.42 | 259672.87 | 330,625 | 190,109,375 | 23.979 | 8.315 | .001739 |
| 576 | 1809.56 | 260576.87 | 331,776 | 191,102,976 | 24.000 | 8.320 | .001736 |
| 577 | 1812.80 | 261482.43 | 332,929 | 192,100,033 | 24.021 | 8.325 | .001733 |
| 578 | 1815.84 | 262388.57 | 334,084 | 193,100,552 | 24.042 | 8.330 | .001730 |
| 579 | 1818.98 | 263298.28 | 335,241 | 194,104,539 | 24.062 | 8.335 | .001727 |
| 580 | 1822.12 | 264208.56 | 336,400 | 195,112,000 | 24.083 | 8.339 | .001724 |
| 581 | 1825.26 | 265120.46 | 337,561 | 196,122,941 | 24.104 | 8.344 | .001721 |
| 582 | 1828.41 | 266033.82 | 338,724 | 197,137,368 | 24.125 | 8.349 | .001718 |
| 583 | 1831.55 | 266948.82 | 339,889 | 198,155,287 | 24.145 | 8.354 | .001715 |
| 584 | 1834.69 | 267865.38 | 341,056 | 199,176,704 | 24.166 | 8.359 | .001712 |
| 585 | 1837.83 | 268783.57 | 342,225 | 200,201,625 | 24.187 | 8.363 | .001709 |

NUMBERS, DIAMETERS AND AREAS, ETC.—(*Cont.*)

| Number or Diameter | Circumference | Circular Area | Square | Cube | Square Root | Cube Root | Reciprocal |
|---|---|---|---|---|---|---|---|
| 586 | 1840.97 | 269703.21 | 343,396 | 201,230,056 | 24.207 | 8.368 | .001706 |
| 587 | 1844.11 | 270624.49 | 344,569 | 202,262,003 | 24.228 | 8.373 | .001704 |
| 588 | 1847.26 | 271547.33 | 345,744 | 203,297,472 | 24.249 | 8.378 | .001701 |
| 589 | 1850.40 | 272471.75 | 346,921 | 204,336,469 | 24.269 | 8.382 | .001698 |
| 590 | 1853.54 | 273397.74 | 348,100 | 205,379,000 | 24.289 | 8.387 | .001695 |
| 591 | 1856.68 | 274325.29 | 349,281 | 206,425,071 | 24.310 | 8.392 | .001692 |
| 592 | 1859.82 | 275254.42 | 350,464 | 207,474,688 | 24.331 | 8.397 | .001689 |
| 593 | 1862.96 | 276185.12 | 351,649 | 208,527,857 | 24.351 | 8.401 | .001686 |
| 594 | 1866.11 | 277117.39 | 352,836 | 209,584,584 | 24.372 | 8.406 | .001684 |
| 595 | 1869.25 | 278051.23 | 354,025 | 210,644,875 | 24.393 | 8.411 | .001681 |
| 596 | 1872.39 | 278986.64 | 355,216 | 211,708,736 | 24.413 | 8.415 | .001678 |
| 597 | 1875.53 | 279923.62 | 356,409 | 212,776,173 | 24.433 | 8.420 | .001675 |
| 598 | 1878.67 | 280862.18 | 357,604 | 213,847,192 | 24.454 | 8.425 | .001672 |
| 599 | 1881.81 | 281802.30 | 358,801 | 214,921,799 | 24.474 | 8.429 | .001669 |
| 600 | 1884.96 | 282744.00 | 360,000 | 216,000,000 | 24.495 | 8.434 | .001667 |
| 601 | 1888.10 | 283687.26 | 361,201 | 217,081,801 | 24.515 | 8.439 | .001664 |
| 602 | 1891.24 | 284632.10 | 362,404 | 218,167,208 | 24.536 | 8.444 | .001661 |
| 603 | 1894.38 | 285578.50 | 363,609 | 219,256,227 | 24.556 | 8.448 | .001658 |
| 604 | 1897.52 | 286526.48 | 364,816 | 220,348,864 | 24.576 | 8.453 | .001656 |
| 605 | 1900.66 | 287476.03 | 366,025 | 221,445,125 | 24.597 | 8.458 | .001653 |
| 606 | 1903.80 | 288426.15 | 367,236 | 222,545,016 | 24.617 | 8.462 | .001650 |
| 607 | 1906.95 | 289379.84 | 368,449 | 223,648,543 | 24.637 | 8.467 | .001647 |
| 608 | 1910.09 | 290334.10 | 369,664 | 224,755,712 | 24.658 | 8.472 | .001645 |
| 609 | 1913.23 | 291289.93 | 370,881 | 225,886,529 | 24.678 | 8.476 | .001642 |
| 610 | 1916.37 | 292247.34 | 372,100 | 226,981,000 | 24.698 | 8.481 | .001639 |
| 611 | 1919.51 | 293206.31 | 373,321 | 228,099,131 | 24.718 | 8.485 | .001637 |
| 612 | 1922.65 | 294166.85 | 374,544 | 229,220,928 | 24.739 | 8.490 | .001634 |
| 613 | 1925.80 | 295128.97 | 375,769 | 230,346,397 | 24.758 | 8.495 | .001631 |
| 614 | 1928.94 | 296092.65 | 376,996 | 231,475,544 | 24.779 | 8.499 | .001629 |
| 615 | 1932.08 | 297057.91 | 378,225 | 232,608,375 | 24.799 | 8.504 | .001626 |
| 616 | 1935.22 | 298024.74 | 379,456 | 233,744,896 | 24.819 | 8.509 | .001623 |
| 617 | 1938.36 | 298993.14 | 380,689 | 234,885,113 | 24.839 | 8.513 | .001621 |
| 618 | 1941.50 | 299963.00 | 381,924 | 236,029,032 | 24.859 | 8.518 | .001618 |
| 619 | 1944.65 | 300934.64 | 383,161 | 237,176,659 | 24.879 | 8.522 | .001616 |
| 620 | 1947.79 | 301907.76 | 384,400 | 238,628,000 | 24.899 | 8.527 | .001613 |
| 621 | 1950.93 | 302882.44 | 385,641 | 239,483,061 | 24.919 | 8.532 | .001610 |
| 622 | 1954.07 | 303858.69 | 386,884 | 240,641,848 | 24.939 | 8.536 | .001608 |
| 623 | 1957.21 | 304836.51 | 388,129 | 241,804,367 | 24.959 | 8.541 | .001605 |
| 624 | 1960.35 | 305815.91 | 389,376 | 242,970,624 | 24.980 | 8.545 | .001603 |
| 625 | 1963.50 | 306796.87 | 390,625 | 244,140,625 | 25.000 | 8.549 | .001600 |
| 626 | 1966.64 | 307779.41 | 391,876 | 245,314,376 | 25.019 | 8.554 | .001597 |
| 627 | 1969.78 | 308763.41 | 393,129 | 246,491,883 | 25.040 | 8.559 | .001595 |
| 628 | 1972.92 | 309749.19 | 394,384 | 247,673,152 | 25.059 | 8.563 | .001592 |
| 629 | 1976.06 | 310736.44 | 395,641 | 248,858,189 | 25.079 | 8.568 | .001590 |
| 630 | 1979.20 | 311725.26 | 396,900 | 250,047,000 | 25.099 | 8.573 | .001587 |

NUMBERS, DIAMETERS AND AREAS, ETC.—(*Cont.*)

| Number or Diameter | Circumference | Circular Area | Square | Cube | Square Root | Cube Root | Reciprocal |
|---|---|---|---|---|---|---|---|
| 631 | 1982.34 | 312715.64 | 398,161 | 251,239,591 | 25.119 | 8.577 | .001585 |
| 632 | 1985.49 | 313707.58 | 399,424 | 252,435,968 | 25.139 | 8.582 | .001582 |
| 633 | 1988.63 | 314701.14 | 400,689 | 253,636,137 | 25.159 | 8.586 | .001580 |
| 634 | 1991.77 | 315696.64 | 401,956 | 254,840,104 | 25.179 | 8.591 | .001577 |
| 635 | 1994.91 | 316692.91 | 403,225 | 256,047,875 | 25.199 | 8.595 | .001575 |
| 636 | 1998.05 | 317691.15 | 404,496 | 257,259,456 | 25.219 | 8.599 | .001572 |
| 637 | 2001.19 | 318690.97 | 405,769 | 258,474,853 | 25.239 | 8.604 | .001570 |
| 638 | 2004.34 | 319692.35 | 407,044 | 259,694,072 | 25.259 | 8.609 | .001567 |
| 639 | 2007.48 | 320695.31 | 408,321 | 260,917,119 | 25.278 | 8.613 | .001565 |
| 640 | 2010.62 | 321699.84 | 409,600 | 262,144,000 | 25.298 | 8.618 | .001563 |
| 641 | 2013.76 | 322705.93 | 410,881 | 263,374,721 | 25.318 | 8.622 | .001560 |
| 642 | 2016.90 | 323713.60 | 412,164 | 264,609,288 | 25.338 | 8.627 | .001558 |
| 643 | 2020.04 | 324722.84 | 413,449 | 265,847,707 | 25.357 | 8.631 | .001555 |
| 644 | 2023.19 | 325733.65 | 414,736 | 267,089,984 | 25.377 | 8.636 | .001553 |
| 645 | 2026.33 | 326746.03 | 416,025 | 268,836,125 | 25.397 | 8.640 | .001550 |
| 646 | 2029.47 | 327759.98 | 417,316 | 269,586,136 | 25.416 | 8.644 | .001548 |
| 647 | 2032.61 | 328775.50 | 418,609 | 270,840,023 | 25.436 | 8.649 | .001546 |
| 648 | 2035.76 | 329792.60 | 419,904 | 272,097,792 | 25.456 | 8.653 | .001543 |
| 649 | 2038.89 | 330811.26 | 421,201 | 273,359,449 | 25.475 | 8.658 | .001541 |
| 650 | 2042.04 | 331831.50 | 422,500 | 274,625,000 | 25.495 | 8.662 | .001538 |
| 651 | 2045.18 | 332853.40 | 423,801 | 275,894,451 | 25.515 | 8.667 | .001536 |
| 652 | 2048.32 | 333876.68 | 425,104 | 277,167,808 | 25.534 | 8.671 | .001534 |
| 653 | 2051.46 | 334901.62 | 426,409 | 278,445,077 | 25.554 | 8.676 | .001531 |
| 654 | 2054.60 | 335928.14 | 427,716 | 279,726,264 | 25.573 | 8.680 | .001529 |
| 655 | 2057.74 | 336956.23 | 429,025 | 281,011,375 | 25.593 | 8.684 | .001527 |
| 656 | 2060.88 | 337985.89 | 430,336 | 282,800,416 | 25.612 | 8.689 | .001524 |
| 657 | 2064.03 | 339017.12 | 431,649 | 283,593,393 | 25.632 | 8.693 | .001522 |
| 658 | 2067.17 | 340049.92 | 432,964 | 284,890,312 | 25.651 | 8.698 | .001520 |
| 659 | 2070.31 | 341084.29 | 434,281 | 286,191,179 | 25.671 | 8.702 | .001517 |
| 660 | 2073.45 | 342120.24 | 435,600 | 287,496,000 | 25.690 | 8.706 | .001515 |
| 661 | 2076.59 | 343157.75 | 436,921 | 288,804,781 | 25.710 | 8.711 | .001513 |
| 662 | 2079.73 | 344196.33 | 438,244 | 290,117,528 | 25.720 | 8.715 | .001511 |
| 663 | 2082.88 | 345237.49 | 439,569 | 291,434,247 | 25.749 | 8.719 | .001508 |
| 664 | 2086.02 | 346279.71 | 440,896 | 292,754,944 | 25.768 | 8.724 | .001506 |
| 665 | 2089.16 | 347323.51 | 442,225 | 294,079,625 | 25.787 | 8.728 | .001504 |
| 666 | 2092.30 | 348368.88 | 443,556 | 295,408,296 | 25.807 | 8.733 | .001502 |
| 667 | 2095.44 | 349416.40 | 444,889 | 296,740,963 | 25.826 | 8.737 | .001499 |
| 668 | 2098.58 | 350464.32 | 446,224 | 298,077,632 | 25.846 | 8.742 | .001497 |
| 669 | 2101.73 | 351514.30 | 447,561 | 299,418,309 | 25.865 | 8.746 | .001495 |
| 670 | 2104.87 | 352566.06 | 448,900 | 300,763,000 | 25.884 | 8.750 | .001493 |
| 671 | 2108.01 | 353619.28 | 450,241 | 302,111,711 | 25.904 | 8.753 | .001490 |
| 672 | 2111.15 | 354674.07 | 451,584 | 303,464,448 | 25.923 | 8.759 | .001488 |
| 673 | 2114.29 | 355730.43 | 452,929 | 304,821,217 | 25.942 | 8.763 | .001486 |
| 674 | 2117.43 | 356788.37 | 454,276 | 306,182,024 | 25.961 | 8.768 | .001484 |
| 675 | 2120.58 | 357847.87 | 455,625 | 307,546,875 | 25.981 | 8.772 | .001481 |

NUMBERS, DIAMETERS AND AREAS, ETC.—(*Cont.*)

| Number or Diameter | Circum-ference | Circular Area | Square | Cube | Square Root | Cube Root | Reciprocal |
|---|---|---|---|---|---|---|---|
| 676 | 2123.72 | 358908.95 | 456,976 | 308,915,776 | 26.000 | 8.776 | .001479 |
| 677 | 2126.86 | 359971.59 | 458,329 | 310,288,733 | 26.019 | 8.781 | .001477 |
| 678 | 2130.00 | 361035.81 | 459,684 | 311,665,752 | 26.038 | 8.785 | .001475 |
| 679 | 2133.14 | 362101.60 | 461,041 | 313,046,839 | 26.058 | 8.789 | .001473 |
| 680 | 2136.28 | 363168.96 | 462,400 | 314,432,000 | 26.077 | 8.794 | .001471 |
| 681 | 2139.42 | 364237.88 | 463,761 | 315,821,241 | 26.096 | 8.798 | .001468 |
| 682 | 2142.57 | 365308.38 | 465,124 | 317,214,568 | 26.115 | 8.802 | .001466 |
| 683 | 2145.71 | 366380.40 | 466,489 | 318,611,987 | 26.134 | 8.807 | .001464 |
| 684 | 2148.85 | 367454.10 | 467,856 | 320,013,504 | 26.153 | 8.811 | .001462 |
| 685 | 2151.99 | 368529.31 | 469,225 | 321,419,125 | 26.172 | 8.815 | .001460 |
| 686 | 2155.13 | 369600.60 | 470,596 | 322,828,856 | 26.192 | 8.819 | .001458 |
| 687 | 2158.27 | 370684.45 | 471,969 | 324,242,703 | 26.211 | 8.824 | .001456 |
| 688 | 2161.42 | 371764.37 | 473,344 | 325,660,672 | 26.229 | 8.828 | .001453 |
| 689 | 2164.56 | 372845.87 | 474,721 | 327,082,769 | 26.249 | 8.832 | .001451 |
| 690 | 2167.70 | 373928.94 | 476,100 | 328,509,000 | 26.268 | 8.836 | .011449 |
| 691 | 2170.84 | 375013.57 | 477,481 | 329,939,371 | 26.287 | 8.841 | .001447 |
| 692 | 2173.98 | 376099.78 | 478,864 | 331,373,888 | 26.306 | 8.845 | .001445 |
| 693 | 2177.12 | 377187.56 | 480,249 | 332,812,557 | 26.325 | 8.849 | .001443 |
| 694 | 2180.27 | 378276.91 | 481,636 | 334,255,384 | 26.344 | 8.853 | .001441 |
| 695 | 2183.41 | 379367.83 | 483,025 | 335,702,375 | 26.363 | 8.858 | .001439 |
| 696 | 2186.55 | 380460.32 | 484,416 | 337,153,536 | 26.382 | 8.862 | .001437 |
| 697 | 2189.69 | 381554.38 | 485,809 | 338,608,873 | 26.401 | 8.866 | .001435 |
| 698 | 2192.83 | 382650.02 | 487,204 | 340,068,392 | 26.419 | 8.870 | .001433 |
| 699 | 2195.97 | 383747.22 | 488,601 | 341,532,099 | 26.439 | 8.875 | .001431 |
| 700 | 2199.12 | 384846.00 | 490,000 | 343,000,000 | 26.457 | 8.879 | .001429 |
| 701 | 2202.26 | 385949.52 | 491,401 | 344,472,101 | 26.476 | 8.883 | .001427 |
| 702 | 2205.40 | 387048.26 | 492,804 | 345,948,088 | 26.495 | 8.887 | .001425 |
| 703 | 2208.54 | 388151.74 | 494,209 | 347,428,927 | 26.514 | 8.892 | .001422 |
| 704 | 2211.68 | 389256.80 | 495,616 | 348,913,664 | 26.533 | 8.896 | .001420 |
| 705 | 2214.82 | 390363.43 | 497,025 | 350,402,625 | 26.552 | 8.900 | .001418 |
| 706 | 2217.96 | 391471.63 | 498,436 | 351,895,816 | 26.571 | 8.904 | .001416 |
| 707 | 2221.11 | 392581.40 | 499,849 | 353,393,243 | 26.589 | 8.908 | .001414 |
| 708 | 2224.25 | 393692.74 | 501,264 | 354,894,912 | 26.608 | 8.913 | .001412 |
| 709 | 2227.39 | 394805.65 | 502,681 | 356,400,829 | 26,627 | 8.917 | .001410 |
| 710 | 2230.53 | 395920.14 | 504,100 | 357,911,000 | 26.644 | 8.921 | .001408 |
| 711 | 2233.67 | 397036.19 | 505,521 | 359,425,431 | 26.664 | 8.925 | .001406 |
| 712 | 2236.81 | 398151.81 | 506,944 | 360,944,128 | 26.683 | 8.929 | .001404 |
| 713 | 2239.96 | 399273.01 | 508,369 | 362,467,097 | 26.702 | 8.934 | .001403 |
| 714 | 2243.10 | 400393.73 | 509,796 | 363,994,344 | 26.721 | 8.938 | .001401 |
| 715 | 2246.24 | 401516.11 | 511,225 | 365,525,875 | 26.739 | 8.942 | .001399 |
| 716 | 2249.38 | 402640.02 | 512,656 | 367,061,696 | 26.758 | 8.946 | .001397 |
| 717 | 2252.52 | 403765.50 | 514,089 | 368,601,813 | 26.777 | 8.950 | .001395 |
| 718 | 2255.66 | 404892.54 | 515,524 | 370,146,232 | 26.795 | 8.954 | .001393 |
| 719 | 2258.81 | 406021.16 | 516,961 | 371,694,959 | 26.814 | 8.959 | .001391 |
| 720 | 2261.95 | 407151.36 | 518,400 | 373,248,000 | 26.833 | 8.963 | .001389 |

NUMBERS, DIAMETERS AND AREAS, ETC.—(*Cont.*)

| Number or Diameter | Circumference | Circular Area | Square | Cube | Square Root | Cube Root | Reciprocal |
|---|---|---|---|---|---|---|---|
| 721 | 2265.09 | 408283.32 | 519,841 | 374,805,361 | 26.851 | 8.967 | .001387 |
| 722 | 2268.23 | 409416.45 | 521,284 | 376,367,048 | 26.870 | 8.971 | .001385 |
| 723 | 2271.37 | 410551.25 | 522,729 | 377,933,067 | 26.889 | 8.975 | .001383 |
| 724 | 2274.51 | 411687.93 | 524,176 | 379,503,424 | 26.907 | 8.979 | .001381 |
| 725 | 2277.66 | 412825.87 | 525,625 | 381,078,125 | 26.926 | 8.983 | .001379 |
| 726 | 2280.80 | 413965.24 | 527,076 | 382,657,176 | 26.944 | 8.988 | .001377 |
| 727 | 2283.94 | 415106.06 | 528,529 | 384,240,583 | 26.963 | 8.992 | .001376 |
| 728 | 2287.08 | 416249.43 | 529,984 | 385,828,352 | 26.991 | 8.996 | .001374 |
| 729 | 2290.22 | 417393.76 | 531,441 | 387,420,489 | 27.000 | 9.000 | .001372 |
| 730 | 2293.36 | 418539.66 | 532,900 | 389,017,000 | 27.018 | 9.004 | .001370 |
| 731 | 2296.50 | 419687.12 | 534,361 | 390,617,891 | 27.037 | 9.008 | .001368 |
| 732 | 2299.65 | 420836.14 | 535,824 | 392,223,168 | 27.055 | 9.012 | .001366 |
| 733 | 2302.79 | 421986.78 | 537,289 | 393,832,837 | 27.074 | 9.016 | .001364 |
| 734 | 2305.93 | 423138.96 | 538,756 | 395,446,904 | 27.092 | 9.020 | .001362 |
| 735 | 2309.07 | 424292.71 | 540,225 | 397,065,375 | 27.111 | 9.023 | .001361 |
| 736 | 2312.21 | 425442.03 | 541,696 | 398,688,256 | 27.129 | 9.029 | .001359 |
| 737 | 2315.35 | 426604.93 | 543,169 | 400,315,553 | 27.148 | 9.033 | .001357 |
| 738 | 2318.50 | 427763.39 | 544,644 | 401,947,272 | 27.166 | 9.037 | .001355 |
| 739 | 2321.64 | 428923.43 | 546,121 | 403,583,419 | 27.184 | 9.041 | .001353 |
| 740 | 2324.78 | 430085.04 | 547,600 | 405,224,000 | 27.203 | 9.045 | .001351 |
| 741 | 2327.92 | 431248.21 | 549,081 | 406,869,021 | 27.221 | 9.049 | .001350 |
| 742 | 2331.06 | 432412.96 | 550,564 | 408,518,488 | 27.239 | 9.053 | .001348 |
| 743 | 2334.20 | 433579.28 | 552,049 | 410,172,407 | 27.258 | 9.057 | .001346 |
| 744 | 2337.35 | 434747.17 | 553,536 | 411,830,784 | 27.276 | 9.061 | .001344 |
| 745 | 2340.49 | 435916.63 | 555,025 | 413,493,625 | 27.295 | 9.065 | .001342 |
| 746 | 2343.63 | 437087.66 | 556,516 | 415,160,936 | 27.313 | 9.069 | .001340 |
| 747 | 2346.77 | 438260.26 | 558,009 | 416,832,723 | 27.331 | 9.073 | .001339 |
| 748 | 2349.91 | 439434.48 | 559,504 | 418,508,992 | 27.349 | 9.077 | .001337 |
| 749 | 2353.05 | 440610.18 | 561,001 | 420,189,749 | 27.368 | 9.081 | .001335 |
| 750 | 2356.20 | 441787.50 | 562,500 | 421,875,000 | 27.386 | 9.086 | .001333 |
| 751 | 2359.34 | 442966.38 | 564,001 | 423,564,751 | 27.404 | 9.089 | .001332 |
| 752 | 2362.48 | 444146.84 | 565,504 | 424,525,900 | 27.423 | 9.094 | .001330 |
| 753 | 2365.62 | 445328.86 | 567,009 | 426,957,777 | 27.441 | 9.098 | .001328 |
| 754 | 2368.76 | 446512.46 | 568,516 | 428,661,064 | 27.459 | 9.102 | .001326 |
| 755 | 2371.90 | 447697.63 | 570,025 | 430,368,875 | 27.477 | 9.106 | .001325 |
| 756 | 2375.04 | 448884.37 | 571,536 | 432,081,216 | 27.495 | 9.109 | .001323 |
| 757 | 2378.19 | 450072.68 | 573,049 | 433,798,093 | 27.514 | 9.114 | .001321 |
| 758 | 2381.33 | 451262.56 | 574,564 | 435,519,512 | 27.532 | 9.118 | .001319 |
| 759 | 2384.47 | 452454.01 | 576,081 | 437,245,479 | 27.549 | 9.122 | .001318 |
| 760 | 2387.61 | 453647.04 | 577,600 | 438,976,000 | 27.568 | 9.126 | .001316 |
| 761 | 2390.75 | 454841.63 | 579,121 | 440,711,081 | 27.586 | 9.129 | .001314 |
| 762 | 2393.89 | 456037.87 | 580,644 | 442,450,728 | 27.604 | 9.134 | .001312 |
| 763 | 2397.04 | 457235.53 | 582,169 | 444,194,947 | 27.622 | 9.138 | .001311 |
| 764 | 2400.18 | 458435.83 | 583,696 | 445,943,744 | 27.640 | 9.142 | .001309 |
| 765 | 2403.32 | 459635.71 | 585,225 | 447,697,125 | 27.659 | 9.146 | .001307 |

NUMBERS, DIAMETERS AND AREAS, ETC.—(*Cont.*)

| Number or Diameter | Circum-ference | Circular Area | Square | Cube | Square Root | Cube Root | Reciprocal |
|---|---|---|---|---|---|---|---|
| 766 | 2406.46 | 460838.16 | 586,756 | 449,455,096 | 27.677 | 9.149 | .001305 |
| 767 | 2409.60 | 462042.18 | 588,289 | 451,217,663 | 27.695 | 9.154 | .001304 |
| 768 | 2412.74 | 463247.76 | 589,824 | 452,984,832 | 27.713 | 9.158 | .001302 |
| 769 | 2415.98 | 464454.92 | 591,361 | 454,756,609 | 27.731 | 9.162 | .001300 |
| 770 | 2419.03 | 465663.66 | 592,900 | 456,533,000 | 27.749 | 9.166 | .001299 |
| 771 | 2422.17 | 466873.96 | 594,441 | 458,314,011 | 27.767 | 9.169 | .001297 |
| 772 | 2425.31 | 468085.83 | 595,984 | 460,099,648 | 27.785 | 9.173 | .001295 |
| 773 | 2428.45 | 469299.27 | 597,529 | 461,889,917 | 27.803 | 9.177 | .001294 |
| 774 | 2431.59 | 470514.29 | 599,076 | 463,684,824 | 27.821 | 9.181 | .001292 |
| 775 | 2434.74 | 471730.87 | 600,625 | 465,484,375 | 27.839 | 9.185 | .001290 |
| 776 | 2437.88 | 472949.03 | 602,176 | 467,288,576 | 27.857 | 9.189 | .001289 |
| 777 | 2441.02 | 474168.75 | 603,729 | 469,097,433 | 27.875 | 9.193 | .001287 |
| 778 | 2444.16 | 475396.05 | 605,284 | 470,910,952 | 27.893 | 9.197 | .001285 |
| 779 | 2447.40 | 476612.92 | 606,841 | 472,729,139 | 27.910 | 9.201 | .001284 |
| 780 | 2450.44 | 477837.36 | 608,400 | 474,552,000 | 27.928 | 9.205 | .001282 |
| 781 | 2453.58 | 479063.36 | 609,961 | 476,379,541 | 27.946 | 9.209 | .001280 |
| 782 | 2456.73 | 480290.94 | 611,524 | 478,211,768 | 27.964 | 9.213 | .001279 |
| 783 | 2459.87 | 481520.10 | 613,089 | 480,048,687 | 27.982 | 9.217 | .001277 |
| 784 | 2463.01 | 482750.82 | 614,656 | 481,890,304 | 28.000 | 9.221 | .001276 |
| 785 | 2466.15 | 483983.11 | 616,225 | 483,736,025 | 28.017 | 9.225 | .001274 |
| 786 | 2469.29 | 485216.97 | 617,796 | 485,587,656 | 28.036 | 9.229 | .001272 |
| 787 | 2472.43 | 486452.41 | 619,369 | 487,443,403 | 28.053 | 9.233 | .001271 |
| 788 | 2475.48 | 487689.73 | 620,944 | 489,303,872 | 28.071 | 9.237 | .001269 |
| 789 | 2478.72 | 488927.99 | 622,521 | 491,169,069 | 28.089 | 9.240 | .001267 |
| 790 | 2481.86 | 490168.14 | 624,100 | 493,039,000 | 28.107 | 9.244 | .001266 |
| 791 | 2485.00 | 491409.85 | 625,681 | 494,913,671 | 28.125 | 9.248 | .001264 |
| 792 | 2488.14 | 492653.14 | 627,264 | 496,793,088 | 28.142 | 9.252 | .001263 |
| 793 | 2491.28 | 493898.20 | 628,849 | 498,677,257 | 28.160 | 9.256 | .001261 |
| 794 | 2494.43 | 495144.43 | 630,436 | 500,566,184 | 28.178 | 9.260 | .001259 |
| 795 | 2497.57 | 496392.43 | 632,025 | 502,459,875 | 28.196 | 9.264 | .001258 |
| 796 | 2500.71 | 497648.40 | 633,616 | 504,358,336 | 28.213 | 9.268 | .001256 |
| 797 | 2503.85 | 498893.14 | 635,209 | 506,261,573 | 28.231 | 9.271 | .001255 |
| 798 | 2506.99 | 500145.86 | 636,804 | 508,169,592 | 28.249 | 9.275 | .001253 |
| 799 | 2510.13 | 501400.14 | 638,401 | 510,082,399 | 28.266 | 9.279 | .001251 |
| 800 | 2513.28 | 502656.00 | 640,000 | 512,000,000 | 28.284 | 9.283 | .001250 |
| 801 | 2516.42 | 503913.42 | 641,601 | 513,922,401 | 28.302 | 9.287 | .001248 |
| 802 | 2519.56 | 505172.43 | 643,204 | 515,849,608 | 28.319 | 9.291 | .001247 |
| 803 | 2522.70 | 506432.98 | 644,809 | 517,781,627 | 28.337 | 9.295 | .001245 |
| 804 | 2525.84 | 507655.52 | 646,416 | 519,718,464 | 28.355 | 9.299 | .001244 |
| 805 | 2528.98 | 508958.83 | 648,025 | 521,660,125 | 28.372 | 9.302 | .001242 |
| 806 | 2532.12 | 510224.11 | 649,636 | 523,606,616 | 28.390 | 9.306 | .001241 |
| 807 | 2535.27 | 511490.96 | 651,249 | 525,557,943 | 28.408 | 9.310 | .001239 |
| 808 | 2538.41 | 512759.38 | 652,864 | 527,514,112 | 28.425 | 9.314 | .001238 |
| 809 | 2541.55 | 514029.37 | 654,481 | 529,474,129 | 28.443 | 9.318 | .001236 |
| 810 | 2544.09 | 515300.94 | 656,100 | 531,441,000 | 28.460 | 9.321 | .001235 |

NUMBERS, DIAMETERS AND AREAS, ETC.—(*Cont.*)

| Number or Diameter | Circumference | Circular Area | Square | Cube | Square Root | Cube Root | Reciprocal |
|---|---|---|---|---|---|---|---|
| 811 | 2547.83 | 516574.07 | 657,721 | 533,411,731 | 28.478 | 9.325 | .001233 |
| 812 | 2550.97 | 517848.77 | 659,344 | 535,387,328 | 28.496 | 9.329 | .001232 |
| 813 | 2554.12 | 519125.05 | 660,969 | 537,366,797 | 28.513 | 9.333 | .001230 |
| 814 | 2557.26 | 520402.85 | 662,596 | 539,353,144 | 28.531 | 9.337 | .001229 |
| 815 | 2560.40 | 521682.31 | 664,225 | 541,343,375 | 28.548 | 9.341 | .001227 |
| 816 | 2563.54 | 522663.30 | 665,856 | 543,338,496 | 28.566 | 9.345 | .001225 |
| 817 | 2566.68 | 524245.86 | 667,489 | 545,338,513 | 28.583 | 9.348 | .001224 |
| 818 | 2569.82 | 525529.98 | 669,124 | 547,343,432 | 28.601 | 9.352 | .001222 |
| 819 | 2572.97 | 526815.68 | 670,761 | 549,353,259 | 28.618 | 9.356 | .001221 |
| 820 | 2576.11 | 528102.96 | 672,400 | 551,368,000 | 28.636 | 9.360 | .001220 |
| 821 | 2579.25 | 529391.80 | 674,041 | 553,387,661 | 28.653 | 9.364 | .001218 |
| 822 | 2582.39 | 530682.21 | 675,684 | 555,412,248 | 28.670 | 9.367 | .001217 |
| 823 | 2585.53 | 531974.39 | 677,329 | 557,441,767 | 28.688 | 9.371 | .001215 |
| 824 | 2588.64 | 533267.75 | 678,976 | 559,476,224 | 28.705 | 9.375 | .001214 |
| 825 | 2591.82 | 534562.87 | 680,625 | 561,515,625 | 28.723 | 9.379 | .001212 |
| 826 | 2594.96 | 535859.57 | 682,276 | 563,559,976 | 28.740 | 9.383 | .001211 |
| 827 | 2598.10 | 537159.83 | 683,929 | 565,609,283 | 28.758 | 9.386 | .001209 |
| 828 | 2601.24 | 538457.62 | 685,584 | 567,663,552 | 28.775 | 9.390 | .001208 |
| 829 | 2604.38 | 539759.08 | 687,241 | 569,722,789 | 28.792 | 9.394 | .001206 |
| 830 | 2607.52 | 541062.06 | 688,900 | 571,787,000 | 28.810 | 9.398 | .001205 |
| 831 | 2610.66 | 542366.60 | 690,561 | 573,856,191 | 28.827 | 9.401 | .001203 |
| 832 | 2613.81 | 543672.72 | 692,224 | 575,930,368 | 28.844 | 9.405 | .001202 |
| 833 | 2616.95 | 544980.52 | 693,889 | 578,009,537 | 28.862 | 9.409 | .001200 |
| 834 | 2620.09 | 546289.68 | 695,556 | 580,093,704 | 28.879 | 9.413 | .001199 |
| 835 | 2623.23 | 547600.51 | 697,225 | 582,182,875 | 28.896 | 9.417 | .001198 |
| 836 | 2626.37 | 548912.91 | 698,896 | 584,277,056 | 28.914 | 9.420 | .001196 |
| 837 | 2629.51 | 550226.89 | 700,569 | 586,376,253 | 28.931 | 9.424 | .001195 |
| 838 | 2632.64 | 551542.43 | 702,244 | 588,480,472 | 28.948 | 9.428 | .001193 |
| 839 | 2635.80 | 552859.58 | 703,921 | 590,589,719 | 28.965 | 9.432 | .001192 |
| 840 | 2638.94 | 554178.24 | 705,600 | 592,704,000 | 28.983 | 9.435 | .001190 |
| 841 | 2642.08 | 555498.49 | 707,281 | 594,823,321 | 29.000 | 9.439 | .001189 |
| 842 | 2645.22 | 556820.32 | 708,964 | 596,947,688 | 29.017 | 9.443 | .001188 |
| 843 | 2648.35 | 558143.72 | 710,649 | 599,077,107 | 29.034 | 9.447 | .001186 |
| 844 | 2651.51 | 559468.69 | 712,336 | 601,211,584 | 29.052 | 9.450 | .001185 |
| 845 | 2654.65 | 560795.23 | 714,025 | 603,351,125 | 29.069 | 9.454 | .001183 |
| 846 | 2657.79 | 562123.34 | 715,716 | 605,495,736 | 29.086 | 9.458 | .001182 |
| 847 | 2660.93 | 563456.82 | 717,409 | 607,645,423 | 29.103 | 9.461 | .001181 |
| 848 | 2664.07 | 564784.28 | 719,104 | 609,800,192 | 29.120 | 9.465 | .001179 |
| 849 | 2667.21 | 566117.10 | 720,801 | 611,960,049 | 29.138 | 9.469 | .001178 |
| 850 | 2670.36 | 567451.59 | 722,500 | 614,125,000 | 29.155 | 9.473 | .001176 |
| 851 | 2673.50 | 568787.46 | 724,201 | 616,295,051 | 29.172 | 9.476 | .001175 |
| 852 | 2676.64 | 570125.00 | 725,904 | 618,470,208 | 29.189 | 9.480 | .001174 |
| 853 | 2679.78 | 571464.10 | 727,609 | 620,650,477 | 29.206 | 9.483 | .001172 |
| 854 | 2682.92 | 572804.78 | 729,316 | 622,835,864 | 29.223 | 9.487 | .001171 |
| 855 | 2686.06 | 574147.03 | 731,025 | 625,026,374 | 29.240 | 9.491 | .001170 |

NUMBERS, DIAMETERS AND AREAS, ETC.—(*Cont.*)

| Number or Diameter | Circumference | Circular Area | Square | Cube | Square Root | Cube Root | Reciprocal |
|---|---|---|---|---|---|---|---|
| 856 | 2689.20 | 575490.85 | 732,736 | 627,222,016 | 29.257 | 9.495 | .001168 |
| 857 | 2692.35 | 576836.24 | 734,449 | 629,422,793 | 29.274 | 9.499 | .001167 |
| 858 | 2695.49 | 578183.20 | 736,164 | 631,628,712 | 29.292 | 9.502 | .001166 |
| 859 | 2698.63 | 579531.73 | 737,881 | 633,839,779 | 29.309 | 9.506 | .001164 |
| 860 | 2701.77 | 580881.84 | 739,600 | 636,056,000 | 29.326 | 9.509 | .001163 |
| 861 | 2704.91 | 582233.51 | 741,321 | 638,277,381 | 29.343 | 9.513 | .001161 |
| 862 | 2708.05 | 583586.75 | 743,044 | 640,503,928 | 29.360 | 9.517 | .001160 |
| 863 | 2711.20 | 584941.57 | 744,769 | 642,735,647 | 29.377 | 9.520 | .001159 |
| 864 | 2714.34 | 586297.95 | 746,496 | 644,972,544 | 29.394 | 9.524 | .001157 |
| 865 | 2717.48 | 587655.91 | 748,225 | 647,214,625 | 29.411 | 9.528 | .001156 |
| 866 | 2720.66 | 589015.41 | 749,956 | 649,461,896 | 29.428 | 9.532 | .001155 |
| 867 | 2723.76 | 590376.54 | 751,689 | 651,714,363 | 29.445 | 9.535 | .001153 |
| 868 | 2726.90 | 591739.20 | 753,424 | 653,972,032 | 29.462 | 9.539 | .001152 |
| 869 | 2730.05 | 593103.44 | 755,161 | 656,234,909 | 29.479 | 9.543 | .001151 |
| 870 | 2733.19 | 594469.26 | 756,900 | 658,503,000 | 29.496 | 9.546 | .001149 |
| 871 | 2736.33 | 595836.44 | 758,641 | 660,776,311 | 29.513 | 9.550 | .001148 |
| 872 | 2739.87 | 597205.59 | 760,384 | 663,054,848 | 29.529 | 9.554 | .001147 |
| 873 | 2742.61 | 598576.91 | 762,129 | 665,338,617 | 29.546 | 9.557 | .001145 |
| 874 | 2745.75 | 599948.21 | 763,876 | 667,627,624 | 29.563 | 9.561 | .001144 |
| 875 | 2748.90 | 601321.87 | 765,625 | 669,921,875 | 29.580 | 9.565 | .001143 |
| 876 | 2752.04 | 602697.11 | 767,376 | 672,221,376 | 29.597 | 9.568 | .001142 |
| 877 | 2755.18 | 604073.91 | 769,129 | 674,526,133 | 29.614 | 9.572 | .001140 |
| 878 | 2758.32 | 605451.49 | 770,884 | 676,836,152 | 29.631 | 9.575 | .001139 |
| 879 | 2761.46 | 606832.24 | 772,641 | 679,151,439 | 29.648 | 9.579 | .001138 |
| 880 | 2764.60 | 608213.76 | 774,400 | 681,472,000 | 29.665 | 9.583 | .001136 |
| 881 | 2767.74 | 609596.84 | 776,161 | 683,797,841 | 29.682 | 9.586 | .001135 |
| 882 | 2770.89 | 610981.50 | 777,924 | 686,128,968 | 29.698 | 9.590 | .001134 |
| 883 | 2774.03 | 612367.74 | 779,689 | 688,465,387 | 29.715 | 9.594 | .001133 |
| 884 | 2777.17 | 613755.54 | 781,456 | 690,807,104 | 29.732 | 9.597 | .001131 |
| 885 | 2780.31 | 615144.91 | 783,225 | 693,154,125 | 29.749 | 9.601 | .001130 |
| 886 | 2783.45 | 616535.85 | 784,996 | 695,506,456 | 29.766 | 9.604 | .001129 |
| 887 | 2786.59 | 617928.37 | 786,769 | 697,864,103 | 29.782 | 9.608 | .001127 |
| 888 | 2789.75 | 619322.45 | 788,544 | 700,227,072 | 29.799 | 9.612 | .001126 |
| 889 | 2792.88 | 620718.11 | 790,321 | 702,595,369 | 29.816 | 9.615 | .001125 |
| 890 | 2796.02 | 622115.34 | 792,100 | 704,969,000 | 29.833 | 9.619 | .001124 |
| 891 | 2799.16 | 623514.13 | 793,881 | 707,347,971 | 29.850 | 9.623 | .001122 |
| 892 | 2802.30 | 624914.50 | 795,664 | 709,732,288 | 29.866 | 9.626 | .001121 |
| 893 | 2805.44 | 626316.44 | 797,449 | 712,121,957 | 29.883 | 9.630 | .001120 |
| 894 | 2808.59 | 627719.95 | 799,236 | 714,516,984 | 29.900 | 9.633 | .001119 |
| 895 | 2811.73 | 629120.35 | 801,025 | 716,917,375 | 29.916 | 9.637 | .001118 |
| 896 | 2814.87 | 630531.68 | 802,816 | 719,323,136 | 29.933 | 9.640 | .001116 |
| 897 | 2818.82 | 631939.90 | 804,609 | 721,734,273 | 29.950 | 9.644 | .001115 |
| 898 | 2821.15 | 633349.70 | 806,404 | 724,150,792 | 29.967 | 9.648 | .001114 |
| 899 | 2824.29 | 634768.13 | 808,201 | 726,572,699 | 29.983 | 9.651 | .001112 |
| 900 | 2827.44 | 636174.00 | 810,000 | 729,000,000 | 30.000 | 9.655 | .001111 |

NUMBERS, DIAMETERS AND AREAS, ETC.—(*Cont.*)

| Number or Diameter | Circumference | Circular Area | Square | Cube | Square Root | Cube Root | Reciprocal |
|---|---|---|---|---|---|---|---|
| 901 | 2830.58 | 637588.50 | 811,804 | 731,432,701 | 30.017 | 9.658 | .001110 |
| 902 | 2833.72 | 639004.58 | 813,604 | 733,870,808 | 30.033 | 9.662 | .001109 |
| 903 | 2836.86 | 640422.22 | 815,409 | 736,314,327 | 30.050 | 9.666 | .001107 |
| 904 | 2840.00 | 641841.44 | 817,216 | 738,763,264 | 30.066 | 9.669 | .001106 |
| 905 | 2843.14 | 643262.23 | 819,025 | 741,217,625 | 30.083 | 9.673 | .001105 |
| 906 | 2846.28 | 644684.74 | 820,836 | 743,677,416 | 30.100 | 9.676 | .001104 |
| 907 | 2849.43 | 646108.52 | 822,649 | 746,142,643 | 30.116 | 9.680 | .001103 |
| 908 | 2852.57 | 647534.02 | 824,464 | 748,613,312 | 30.133 | 9.683 | .001101 |
| 909 | 2855.71 | 648961.09 | 826,281 | 751,089,429 | 30.150 | 9.687 | .001100 |
| 910 | 2858.85 | 650389.74 | 828,100 | 753,571,000 | 30.163 | 9.690 | .001099 |
| 911 | 2861.99 | 651819.95 | 829,921 | 756,058,031 | 30.183 | 9.694 | .001098 |
| 912 | 2865.13 | 653251.73 | 831,744 | 758,550,528 | 30.199 | 9.698 | .001096 |
| 913 | 2868.29 | 654689.09 | 833,569 | 761,048,497 | 30.216 | 9.701 | .001095 |
| 914 | 2871.42 | 656120.81 | 835,396 | 763,551,944 | 30.232 | 9.705 | .001094 |
| 915 | 2874.56 | 657556.51 | 837,225 | 766,060,874 | 30.249 | 9.708 | .001093 |
| 916 | 2877.70 | 658994.58 | 839,056 | 768,575,296 | 30.265 | 9.712 | .001092 |
| 917 | 2880.84 | 660432.22 | 840,880 | 771,095,213 | 30.282 | 9.715 | .001091 |
| 918 | 2883.98 | 661875.42 | 842,724 | 773,620,632 | 30.298 | 9.718 | .001089 |
| 919 | 2887.13 | 663318.20 | 844,561 | 776,151,559 | 30.315 | 9.722 | .001088 |
| 920 | 2890.27 | 664762.56 | 846,400 | 778,688,000 | 30.331 | 9.726 | .001087 |
| 921 | 2893.41 | 666208.48 | 848,241 | 781,229,961 | 30.348 | 9.729 | .001086 |
| 922 | 2896.55 | 667655.97 | 850,084 | 783,777,448 | 30.364 | 9.733 | .001085 |
| 923 | 2899.69 | 669101.61 | 851,929 | 786,330,467 | 30.381 | 9.736 | .001083 |
| 924 | 2902.83 | 670555.67 | 853,776 | 788,889,024 | 30.397 | 9.740 | .101082 |
| 925 | 2905.98 | 672007.87 | 855,625 | 791,453,125 | 30.414 | 9.743 | .001081 |
| 926 | 2909.12 | 673461.65 | 857,476 | 794,022,776 | 30.430 | 9.747 | .001080 |
| 927 | 2912.26 | 674916.99 | 859,329 | 796,597,983 | 30.447 | 9.750 | .001079 |
| 928 | 2915.40 | 676373.91 | 861,184 | 799,178,752 | 30.463 | 9.754 | .001078 |
| 929 | 2918.54 | 677832.40 | 863,041 | 801,765,089 | 30.479 | 9.757 | .001076 |
| 930 | 2921.68 | 679292.46 | 864,900 | 804,357,000 | 30.496 | 9.761 | .001075 |
| 931 | 2924.82 | 680754.08 | 866,761 | 806,954,491 | 30.512 | 9.764 | .001074 |
| 932 | 2927.97 | 682217.30 | 868,624 | 809,557,568 | 30.529 | 9.768 | .001073 |
| 933 | 2931.11 | 683682.06 | 870,489 | 812,166,237 | 30.545 | 9.771 | .001072 |
| 934 | 2934.25 | 685148.40 | 872,356 | 814,780,504 | 30.561 | 9.775 | .001071 |
| 935 | 2937.39 | 686616.31 | 874,225 | 817,400,375 | 30.578 | 9.778 | .001070 |
| 936 | 2940.53 | 688085.79 | 876,096 | 820,025,856 | 30.594 | 9.783 | .001068 |
| 937 | 2943.67 | 689556.85 | 877,969 | 822,656,953 | 30.610 | 9.785 | .001067 |
| 938 | 2946.82 | 691029.47 | 879,844 | 825,293,672 | 30.627 | 9.789 | .001066 |
| 939 | 2949.96 | 692503.67 | 881,721 | 827,936,019 | 30.643 | 9.792 | .001065 |
| 940 | 2953.10 | 693979.44 | 883,600 | 830,584,000 | 30.659 | 9.796 | .001064 |
| 941 | 2956.24 | 695456.77 | 885,481 | 833,237,621 | 30.676 | 9.799 | .001063 |
| 942 | 2959.38 | 696935.68 | 887,364 | 835,896,888 | 30.692 | 9.803 | .001062 |
| 943 | 2962.43 | 698416.14 | 889,249 | 838,561,807 | 30.708 | 9.806 | .001060 |
| 944 | 2965.67 | 699898.21 | 891,136 | 841,232,384 | 30.724 | 9.810 | .001059 |
| 945 | 2968.81 | 701381.83 | 893,025 | 843,908,625 | 30.741 | 9.813 | .001058 |

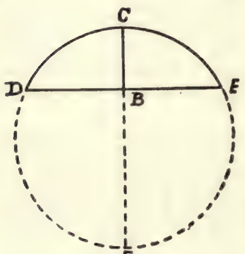
NUMBERS, DIAMETERS AND AREAS, ETC.—(*Cont.*)

| Number or Diameter | Circumference | Circular Area | Square | Cube | Square Root | Cube Root | Reciprocal |
|---|---|---|---|---|---|---|---|
| 946 | 2971.95 | 702867.02 | 894,916 | 846,590,536 | 30.757 | 9.817 | .001057 |
| 947 | 2975.09 | 704350.25 | 896,809 | 849,278,123 | 30.773 | 9.820 | .001056 |
| 948 | 2978.23 | 705841.80 | 898,704 | 851,971,392 | 30.790 | 9.823 | .001055 |
| 949 | 2981.37 | 707332.02 | 900,601 | 854,670,349 | 30.806 | 9.827 | .001054 |
| 950 | 2984.52 | 708023.50 | 902,500 | 857,375,000 | 30.822 | 9.830 | .001053 |
| 951 | 2987.66 | 710316.54 | 904,401 | 860,085,351 | 30.838 | 9.834 | .001052 |
| 952 | 2990.72 | 711811.16 | 906,304 | 862,801,408 | 30.854 | 9.837 | .001050 |
| 953 | 2993.94 | 713307.34 | 908,209 | 865,523,177 | 30.871 | 9.841 | .001049 |
| 954 | 2997.08 | 714805.10 | 910,116 | 868,250,664 | 30.887 | 9.844 | .001048 |
| 955 | 3000.22 | 716304.43 | 912,025 | 870,983,875 | 30.903 | 9.848 | .001047 |
| 956 | 3003.36 | 717805.33 | 913,936 | 873,722,816 | 30.919 | 9.851 | .001046 |
| 957 | 3006.51 | 719307.80 | 915,849 | 876,467,493 | 30.935 | 9.854 | .001045 |
| 958 | 3009.65 | 720811.84 | 917,764 | 879,217,912 | 30.951 | 9.858 | .001044 |
| 959 | 3012.79 | 722317.45 | 919,681 | 881,974,079 | 30.968 | 9.861 | .001043 |
| 960 | 3015.90 | 723824.64 | 921,600 | 884,736,000 | 30.984 | 9.865 | .001042 |
| 961 | 3019.07 | 725333.39 | 923,521 | 887,503,681 | 31.000 | 9.868 | .001041 |
| 962 | 3022.21 | 726843.71 | 925,444 | 890,277,128 | 31.016 | 9.872 | .001040 |
| 963 | 3025.36 | 728355.61 | 927,369 | 893,056,347 | 31.032 | 9.875 | .001038 |
| 964 | 3028.50 | 729869.07 | 929,296 | 895,841,344 | 31.048 | 9.878 | .001037 |
| 965 | 3031.64 | 731384.11 | 931,225 | 898,632,125 | 31.064 | 9.881 | .001036 |
| 966 | 3034.78 | 732900.72 | 933,156 | 901,428,696 | 31.080 | 9.885 | .001035 |
| 967 | 3037.92 | 734418.90 | 935,089 | 904,231,063 | 31.097 | 9.889 | .001034 |
| 968 | 3041.06 | 735938.64 | 937,024 | 907,039,232 | 31.113 | 9.892 | .001033 |
| 969 | 3044.21 | 737459.96 | 938,961 | 909,853,209 | 31.129 | 9.895 | .001032 |
| 970 | 3047.35 | 738982.86 | 940,900 | 912,673,000 | 31.145 | 9.899 | .001031 |
| 971 | 3050.49 | 740507.32 | 942,841 | 915,498,611 | 31.161 | 9.902 | .001030 |
| 972 | 3053.63 | 742033.35 | 944,784 | 918,330,048 | 31.177 | 9.906 | .001029 |
| 973 | 3056.77 | 743560.95 | 946,729 | 921,167,317 | 31.193 | 9.909 | .001028 |
| 974 | 3059.91 | 745090.13 | 948,676 | 924,010,424 | 31.209 | 9.912 | .001027 |
| 975 | 3063.06 | 746620.87 | 950,625 | 926,859,375 | 31.225 | 9.916 | .001026 |
| 976 | 3066.20 | 748153.19 | 952,576 | 929,714,176 | 31.241 | 9.919 | .001025 |
| 977 | 3069.36 | 749687.07 | 954,529 | 932,574,833 | 31.257 | 9.923 | .001024 |
| 978 | 3072.48 | 751222.53 | 856,484 | 935,441,352 | 31.273 | 9.926 | .001022 |
| 979 | 3075.62 | 752759.56 | 958,441 | 938,313,739 | 31.289 | 9.929 | .001021 |
| 980 | 3078.76 | 754298.16 | 960,400 | 941,192,000 | 31.305 | 9.933 | .001020 |
| 981 | 3081.90 | 755838.32 | 962,361 | 944,076,141 | 31.321 | 9.936 | .001019 |
| 982 | 3085.05 | 757380.06 | 964,324 | 946,966,168 | 31.337 | 9.940 | .001018 |
| 983 | 3088.19 | 758923.38 | 966,289 | 949,862,087 | 31.353 | 9.943 | .001017 |
| 984 | 3091.33 | 760468.26 | 968,256 | 952,763,904 | 31.369 | 9.946 | .001016 |
| 985 | 3094.47 | 762014.71 | 970,225 | 955,671,625 | 31.385 | 9.950 | .001015 |
| 986 | 3097.61 | 763562.73 | 972,196 | 958,585,256 | 31.401 | 9.953 | .001014 |
| 987 | 3100.75 | 765119.33 | 974,169 | 961,504,803 | 31.416 | 9.956 | .001013 |
| 988 | 3103.96 | 766663.49 | 976,144 | 964,430,272 | 31.432 | 9.960 | .001012 |
| 989 | 3107.04 | 768216.23 | 978,121 | 967,361,669 | 31.448 | 9.963 | .001011 |
| 990 | 3110.18 | 769770.54 | 980,100 | 970,299,000 | 31.464 | 9.966 | .001010 |

NUMBERS, DIAMETERS AND AREAS, ETC.—(*Cont.*)

| Number or Diameter | Circumference | Circular Area | Square | Cube | Square Root | Cube Root | Reciprocal |
|---|---|---|---|---|---|---|---|
| 991 | 3113.32 | 771326.41 | 982,081 | 973,242,271 | 31.480 | 9.970 | .001009 |
| 992 | 3116.46 | 772883.86 | 984,064 | 976,191,488 | 31.496 | 9.973 | .001008 |
| 993 | 3119.60 | 774442.88 | 986,049 | 979,146,657 | 31.512 | 9.977 | .001007 |
| 994 | 3122.75 | 776003.47 | 988,036 | 982,107,784 | 31.528 | 9.980 | .001006 |
| 995 | 3125.89 | 777565.63 | 990,025 | 985,074,875 | 31.544 | 9.983 | .001005 |
| 996 | 3129.03 | 779129.36 | 992,016 | 988,047,936 | 31.559 | 9.987 | .001004 |
| 997 | 3132.17 | 780694.66 | 994,009 | 991,026,973 | 31.575 | 9.990 | .001003 |
| 998 | 3135.11 | 782261.54 | 996,004 | 994,011,992 | 31.591 | 9.993 | .001002 |
| 999 | 3138.45 | 783829.98 | 998,001 | 997,002,999 | 31.607 | 9.997 | .001001 |
| 1,000 | 3141.60 | 785400.00 | 1,000,000 | 1,000,000,000 | 31.623 | 10.000 | .001000 |

**To Find the Length of Any Arc of a Circle.**—Rule 1. When the chord of the arc and the versed sine of half the arc are given. To fifteen times the square of the chord, add thirty-three times the square of the versed sine, and reserve the number. To the square of the chord, add four times the square of the versed sine, and the square root of the sum will be twice the chord of half the arc.




Multiply twice the chord of half the arc by ten times the square of the versed sine, divide the product by the reserve number, and add the quotient to twice the chord of half the arc: the sum will be the length of the arc very nearly.

**When the Chord of the Arc and Chord of Half the Arc are Given.**—From the square of the chord of half the arc subtract the square of half the chord of the arc, the remainder will be the square of the versed sine; then proceed as above.

**Rule 2. When the Diameter and the Versed Sine of Half the Arc Are Given.**—From sixty times the diameter subtract twenty-seven times the versed sine, and reserve the number.

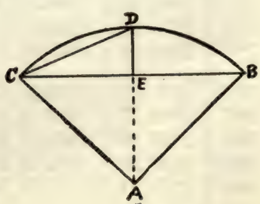
Multiply the diameter by the versed sine, and the square root of the product will be the chord of half the arc.

Multiply twice the chord of half the arc by ten times the versed sine, divide the product by the reserve number, and add the quotient to twice the chord of half the arc; the sum will be the length of the arc very nearly.

NOTE.—1. When the diameter and chord of the arc are given, the versed sine may be found thus: From the square of the diameter subtract the square of the chord, and extract the square root of the remainder. Subtract this root from the diameter and half the remainder will give the versed sine of half the arc.

2. The square of the chord of half the arc being divided by the diameter will give the versed sine, or being divided by the versed sine will give the diameter.

3. The length of the arc may also be found by multiplying together the number of degrees it contains, the radius and the number .01745329.



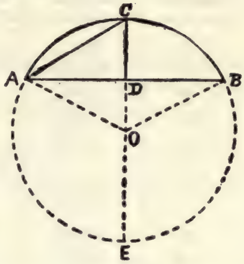

**To Find the Area of a Sector of a Circle.**—Rule: Multiply half the length of the arc of the sector by the radius.

Or, multiply the number of the degrees in the arc by the square of the radius, and by .008727.

NOTE.—If the diameter or radius is not given, add the

square of half the chord of the arc to the square of the versed sine of half the arc; this sum being divided by the versed sine will give the diameter.

**To Find the Area of a Segment of a Circle.**—Rule 1: Find the area of the sector which has the same arc as the segment; also the area of the triangle formed by the radial sides of the sector and the chord of the arc; the difference or the sum of these areas will be the area of the segment, according as it is less or greater than a semicircle.

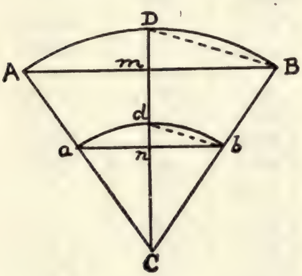



NOTE.—The difference between the versed sine and radius, multiplied by half the chord of the arc, will give the area of the triangle.

Rule 2. Divide the height, or versed sine, by the diameter, and find the quotient in the table of versed sines.

Multiply the number on the right hand of the versed sines by the square of the diameter, and the product will be the area.

NOTE 1.—When the quotient arising from the versed sine divided by the diameter has a remainder or fraction after the third place of decimals; having taken the area answering to the first three figures subtract it from the next following area, multiply the remainder by the said fraction, and add the product to the first area: the sum will be the area for the whole quotient.




NOTE 2.—The table to which this rule refers is formed of the areas of the segments of a circle whose diameter is 1; and which is supposed to be divided by perpendicular chords into 1000 equal parts.

The rule depends upon this property—that the versed sine of similar segments are as the diameters of the circles to which they belong, and the area of those segments as the squares of the diameter; which may be thus demonstrated:

Let A D B A and $a\,d\,b\,a$ be any two similar segments, cut off from the similar sectors A D B C A and $a\,d\,b\,c\,a$, by the chords A B and $a\,b$, and let the perpendicular C D bisect them. Then by similar triangles, D B : $d\,b$ :: B C : $b\,c$ and D B : $d\,b$ :: D $m$ : $d\,n$; whence, by equality, B $c$ : $b\,c$ :: D $m$ : $d\,n$, or 2 B C : 2 $b\,c$ :: D $m$ : $d\,n$.

## LENGTHS OF CIRCULAR ARCS FROM 1° TO 180°

**Given the Degrees. Radius = 1**

In this table, the lengths of circular arcs are given proportionately to that of radius = 1, as determined by the following formula:

Length of arc $= \frac{3.1416}{180} \times$ radius $\times$ number of degrees. The numbers of degrees in the arc are given in the first column, and the length of the arc, as compared with the radius, is given decimally in the second column.

To use this table: Find the proportional length of the arc corresponding to the degrees in the arc, and multiply it by the actual length of the radius; the product is the length of the arc.

*Example*: Required the length of a circular arc corresponding to 62°, the radius = 36.

From the table, 62° = 1.0821.

Then 1.0821 × 36 = 38.9556, the required length.

## Lengths of Circular Arcs from 1° to 180°. Given the Degrees.

Radius = 1.

| Degrees | Length | Degrees | Length | Degrees | Length | Degrees | Length |
|---|---|---|---|---|---|---|---|
| 1 | .0174 | 46 | .8028 | 91 | 1.5882 | 136 | 2.3736 |
| 2 | .0349 | 47 | .8203 | 92 | 1.6057 | 137 | 2.3911 |
| 3 | .0524 | 48 | .8377 | 93 | 1.6231 | 138 | 2.4085 |
| 4 | .0698 | 49 | .8552 | 94 | 1.6406 | 139 | 2.4260 |
| 5 | .0873 | 50 | .8727 | 95 | 1.6581 | 140 | 2.4435 |
| 6 | .0147 | 51 | .8901 | 96 | 1.6755 | 141 | 2.4609 |
| 7 | .0222 | 52 | .9076 | 97 | 1.6930 | 142 | 2.4784 |
| 8 | .0396 | 53 | .9250 | 98 | 1.7104 | 143 | 2.4958 |
| 9 | .0571 | 54 | .9424 | 99 | 1.7279 | 144 | 2.5133 |
| 10 | .1745 | 55 | .9599 | 100 | 1.7453 | 145 | 2.5307 |
| 11 | .1920 | 56 | .9774 | 101 | 1.7628 | 146 | 2.5482 |
| 12 | .2094 | 57 | .9948 | 102 | 1.7802 | 147 | 2.5656 |
| 13 | .2269 | 58 | 1.0123 | 103 | 1.7977 | 148 | 2.5831 |
| 14 | .2443 | 59 | 1.0297 | 104 | 1.8151 | 149 | 2.6005 |
| 15 | .2618 | 60 | 1.0472 | 105 | 1.8326 | 150 | 2.6180 |
| 16 | .2792 | 61 | 1.0646 | 106 | 1.8500 | 151 | 2.6354 |
| 17 | .2967 | 62 | 1.0821 | 107 | 1.8675 | 152 | 2.6529 |
| 18 | .3141 | 63 | 1.0995 | 108 | 1.8849 | 153 | 2.6703 |
| 19 | .3316 | 64 | 1.1170 | 109 | 1.9024 | 154 | 2.6878 |
| 20 | .3491 | 65 | 1.1345 | 110 | 1.9199 | 155 | 2.7053 |
| 21 | .3665 | 66 | 1.1519 | 111 | 1.9373 | 156 | 2.7227 |
| 22 | .3840 | 67 | 1.1694 | 112 | 1.9548 | 157 | 2.7402 |
| 23 | .4014 | 68 | 1.1868 | 113 | 1.9722 | 158 | 2.7576 |
| 24 | .4189 | 69 | 1.2043 | 114 | 1.9897 | 159 | 2.7751 |
| 25 | .4363 | 70 | 1.2217 | 115 | 2.0071 | 160 | 2.7925 |
| 26 | .4538 | 71 | 1.2392 | 116 | 2.0246 | 161 | 2.8100 |
| 27 | .4712 | 72 | 1.2566 | 117 | 2.0420 | 162 | 2.8274 |
| 28 | .4887 | 73 | 1.2741 | 118 | 2.0595 | 163 | 2.8449 |
| 29 | .5061 | 74 | 1.2915 | 119 | 2.0769 | 164 | 2.8623 |
| 30 | .5236 | 75 | 1.3090 | 120 | 2.0944 | 165 | 2.8798 |
| 31 | .5410 | 76 | 1.3264 | 121 | 2.1118 | 166 | 2.8972 |
| 32 | .5585 | 77 | 1.3439 | 122 | 2.1293 | 167 | 2.9147 |
| 33 | .5759 | 78 | 1.3613 | 123 | 2.1467 | 168 | 2.9321 |
| 34 | .5934 | 79 | 1.3788 | 124 | 2.1642 | 169 | 2.9496 |
| 35 | .6109 | 80 | 1.3963 | 125 | 2.1817 | 170 | 2.9670 |
| 36 | .6283 | 81 | 1.4137 | 126 | 2.1991 | 171 | 2.9845 |
| 37 | .6458 | 82 | 1.4312 | 127 | 2.2166 | 172 | 3.0020 |
| 38 | .6632 | 83 | 1.4486 | 128 | 2.2304 | 173 | 3.0194 |
| 39 | .6807 | 84 | 1.4661 | 129 | 2.2515 | 174 | 3.0369 |
| 40 | .6981 | 85 | 1.4835 | 130 | 2.2689 | 175 | 3.0543 |
| 41 | .7156 | 86 | 1.5010 | 131 | 2.2864 | 176 | 3.0718 |
| 42 | .7330 | 87 | 1.5184 | 132 | 2.3038 | 177 | 3.0892 |
| 43 | .7505 | 88 | 1.5359 | 133 | 2.3213 | 178 | 3.1067 |
| 44 | .7679 | 89 | 1.5533 | 134 | 2.3387 | 179 | 3.1241 |
| 45 | .7854 | 90 | 1.5708 | 135 | 2.3562 | 180 | 3.1416 |

## LENGTHS OF CIRCULAR ARCS, UP TO A SEMICIRCLE

### Given the Height. Chord = 1

In this table the chord is taken = 1, and the rise or height of the arc, expressed decimally as compared with the chord, is given in the first column. The length of the arc relatively to the chord is given in the second column.

To use this table, divide the height of the arc by the chord for the proportional height of the arc, which find in the first column of the table. The proportional length of the arc corresponding to it, being multiplied by the actual length of the chord, gives the actual length of the arc.

NOTE.—The length of an arc of a circle may be found nearly thus: Subtract the chord of the whole arc from eight times the chord of half the arc, one-third of the remainder is the length nearly.

LENGTHS OF CIRCULAR ARCS, UP TO A SEMICIRCLE. GIVEN THE HEIGHT.

Chord = 1.

| Height | Length | Height | Length | Height | Length | Height | Length |
|---|---|---|---|---|---|---|---|
| .100 | 1.02645 | | | | | | |
| .101 | 1.02698 | .131 | 1.04515 | .161 | 1.06775 | .191 | 1.09461 |
| .102 | 1.02752 | .132 | 1.04584 | .162 | 1.06858 | .192 | 1.09557 |
| .103 | 1.02806 | .133 | 1.04652 | .163 | 1.06941 | .193 | 1.09654 |
| .104 | 1.02860 | .134 | 1.04722 | .164 | 1.07025 | .194 | 1.09752 |
| .105 | 1.02914 | .135 | 1.04792 | .165 | 1.07109 | .195 | 1.09850 |
| .106 | 1.02970 | .136 | 1.04862 | .166 | 1.07194 | .196 | 1.09949 |
| .107 | 1.03026 | .137 | 1.04932 | .167 | 1.07279 | .197 | 1.10048 |
| .108 | 1.03082 | .138 | 1.05003 | .168 | 1.07365 | .198 | 1.10147 |
| .109 | 1.03139 | .139 | 1.05075 | .169 | 1.07451 | .199 | 1.10247 |
| .110 | 1.03196 | .140 | 1.05147 | .170 | 1.07537 | .200 | 1.10348 |
| .111 | 1.03254 | .141 | 1.05220 | .171 | 1.07624 | .201 | 1.10447 |
| .112 | 1.03312 | .142 | 1.05293 | .172 | 1.07711 | .202 | 1.10548 |
| .113 | 1.03371 | .143 | 1.05367 | .173 | 1.07799 | .203 | 1.10650 |
| .114 | 1.03430 | .144 | 1.05441 | .174 | 1.07888 | .204 | 1.10752 |
| .115 | 1.03490 | .145 | 1.05516 | .175 | 1.07977 | .205 | 1.10855 |
| .116 | 1.03551 | .146 | 1.05591 | .176 | 1.08066 | .206 | 1.10958 |
| .117 | 1.03611 | .147 | 1.05667 | .177 | 1.08156 | .207 | 1.11062 |
| .118 | 1.03672 | .148 | 1.05743 | .178 | 1.08246 | .208 | 1.11165 |
| .119 | 1.03734 | .149 | 1.05819 | .179 | 1.08337 | .209 | 1.11269 |
| .120 | 1.03797 | .150 | 1.05896 | .180 | 1.08428 | .210 | 1.11374 |
| .121 | 1.03860 | .151 | 1.05973 | .181 | 1.08519 | .211 | 1.11479 |
| .122 | 1.03923 | .152 | 1.06051 | .182 | 1.08611 | .212 | 1.11584 |
| .123 | 1.03987 | .153 | 1.06130 | .183 | 1.08704 | .213 | 1.11692 |
| .124 | 1.04051 | .154 | 1.06209 | .184 | 1.08797 | .214 | 1.11796 |
| .125 | 1.04116 | .155 | 1.06288 | .185 | 1.08890 | .215 | 1.11904 |
| .126 | 1.04181 | .156 | 1.06368 | .186 | 1.08984 | .216 | 1.12011 |
| .127 | 1.04247 | .157 | 1.06449 | .187 | 1.09079 | .217 | 1.12118 |
| .128 | 1.04313 | .158 | 1.06530 | .188 | 1.09174 | .218 | 1.12225 |
| .129 | 1.04380 | .159 | 1.06611 | .189 | 1.09269 | .219 | 1.12334 |
| .130 | 1.04447 | .160 | 1.06693 | .190 | 1.09365 | .220 | 1.12445 |

LENGTHS OF CIRCULAR ARCS—(*Cont.*)

| Height | Length | Height | Length | Height | Length | Height | Length |
|---|---|---|---|---|---|---|---|
| .221 | 1.12556 | .266 | 1.17912 | .311 | 1.24070 | .356 | 1.30954 |
| .222 | 1.12663 | .267 | 1.18040 | .312 | 1.24216 | .357 | 1.31115 |
| .223 | 1.12774 | .268 | 1.18162 | .313 | 1.24360 | .358 | 1.31276 |
| .224 | 1.12885 | .269 | 1.18294 | .314 | 1.24506 | .359 | 1.31437 |
| .225 | 1.12997 | .270 | 1.18428 | .315 | 1.24654 | .360 | 1.31599 |
| .226 | 1.13108 | .271 | 1.18557 | .316 | 1.24801 | .361 | 1.31761 |
| .227 | 1.13219 | .272 | 1.18688 | .317 | 1.24946 | .362 | 1.31923 |
| .228 | 1.13331 | .273 | 1.18819 | .318 | 1.25095 | .363 | 1.32086 |
| .229 | 1.13444 | .274 | 1.18969 | .319 | 1.25243 | .364 | 1.32249 |
| .230 | 1.13557 | .275 | 1.19082 | .320 | 1.25391 | .365 | 1.32413 |
| .231 | 1.13671 | .276 | 1.19214 | .321 | 1.25539 | .366 | 1.32577 |
| .232 | 1.13786 | .277 | 1.19345 | .322 | 1.25686 | .367 | 1.32741 |
| .233 | 1.13903 | .278 | 1.19477 | .323 | 1.25836 | .368 | 1.32905 |
| .234 | 1.14020 | .279 | 1.19610 | .324 | 1.25987 | .369 | 1.33069 |
| .235 | 1.14136 | .280 | 1.19743 | .325 | 1.26137 | .370 | 1.33234 |
| .236 | 1.14247 | .281 | 1.19887 | .326 | 1.26286 | .371 | 1.33399 |
| .237 | 1.14363 | .282 | 1.20011 | .327 | 1.26437 | .372 | 1.33564 |
| .238 | 1.14480 | .283 | 1.20146 | .328 | 1.26588 | .373 | 1.33730 |
| .239 | 1.14597 | .284 | 1.20282 | .329 | 1.26740 | .374 | 1.33896 |
| .240 | 1.14714 | .285 | 1.20419 | .330 | 1.26892 | .375 | 1.34063 |
| .241 | 1.14831 | .286 | 1.20558 | .331 | 1.27044 | .376 | 1.34229 |
| .242 | 1.14949 | .287 | 1.20696 | .332 | 1.27196 | .377 | 1.34396 |
| .243 | 1.15067 | .288 | 1.20828 | .333 | 1.27349 | .378 | 1.34563 |
| .244 | 1.15186 | .289 | 1.20967 | .334 | 1.27502 | .379 | 1.34731 |
| .245 | 1.15308 | .290 | 1.21202 | .335 | 1.27656 | .380 | 1.34899 |
| .246 | 1.15429 | .291 | 1.21239 | .336 | 1.27810 | .381 | 1.35068 |
| .247 | 1.15549 | .292 | 1.21381 | .337 | 1.27864 | .382 | 1.35237 |
| .248 | 1.15670 | .293 | 1.21520 | .338 | 1.28118 | .383 | 1.35406 |
| .249 | 1.15791 | .294 | 1.21658 | .339 | 1.28273 | .384 | 1.35575 |
| .250 | 1.15912 | .295 | 1.21794 | .340 | 1.28428 | .385 | 1.35744 |
| .251 | 1.16033 | .296 | 1.21926 | .341 | 1.28583 | .386 | 1.35914 |
| .252 | 1.16157 | .297 | 1.22061 | .342 | 1.28739 | .387 | 1.36084 |
| .253 | 1.16279 | .298 | 1.22203 | .343 | 1.28895 | .388 | 1.36254 |
| .254 | 1.16402 | .299 | 1.22347 | .344 | 1.29052 | .389 | 1.36425 |
| .255 | 1.16526 | .300 | 1.22495 | .345 | 1.29209 | .390 | 1.36586 |
| .256 | 1.16649 | .301 | 1.22635 | .346 | 1.29366 | .391 | 1.36767 |
| .257 | 1.16774 | .302 | 1.22776 | .347 | 1.29523 | .392 | 1.36939 |
| .258 | 1.16899 | .303 | 1.22918 | .348 | 1.29681 | .393 | 1.37111 |
| .259 | 1.17024 | .304 | 1.23061 | .349 | 1.29839 | .394 | 1.37283 |
| .260 | 1.17150 | .305 | 1.23205 | .350 | 1.29997 | .395 | 1.37455 |
| .261 | 1.17275 | .306 | 1.23349 | .351 | 1.30156 | .396 | 1.37628 |
| .262 | 1.17401 | .307 | 1.23494 | .352 | 1.30315 | .397 | 1.37801 |
| .263 | 1.17527 | .308 | 1.23636 | .353 | 1.30474 | .398 | 1.37974 |
| .264 | 1.17655 | .309 | 1.23780 | .354 | 1.30634 | .399 | 1.38148 |
| .265 | 1.17784 | .310 | 1.23925 | .355 | 1.30794 | .400 | 1.38322 |

LENGTHS OF CIRCULAR ARCS—(*Cont.*)

| Height | Length | Height | Length | Height | Length | Height | Length |
|---|---|---|---|---|---|---|---|
| .401 | 1.38496 | .426 | 1.42945 | .451 | 1.47565 | .476 | 1.52346 |
| .402 | 1.38671 | .427 | 1.43127 | .452 | 1.47753 | .477 | 1.52541 |
| .403 | 1.38846 | .428 | 1.43309 | .453 | 1.47942 | .478 | 1.52736 |
| .404 | 1.39021 | .429 | 1.43491 | .454 | 1.48131 | .479 | 1.52931 |
| .405 | 1.39196 | .430 | 1.43673 | .455 | 1.48320 | .480 | 1.53126 |
| .406 | 1.39372 | .431 | 1.43856 | .456 | 1.48509 | .481 | 1.53322 |
| .407 | 1.39548 | .432 | 1.44039 | .457 | 1.48699 | .482 | 1.53518 |
| .408 | 1.39724 | .433 | 1.44222 | .458 | 1.48889 | .483 | 1.53714 |
| .409 | 1.39900 | .434 | 1.44405 | .459 | 1.49079 | .484 | 1.53910 |
| .410 | 1.40077 | .435 | 1.44589 | .460 | 1.49269 | .485 | 1.54106 |
| .411 | 1.40254 | .436 | 1.44773 | .461 | 1.49460 | .486 | 1.54302 |
| .412 | 1.40432 | .437 | 1.44957 | .462 | 1.49651 | .487 | 1.54499 |
| .413 | 1.40610 | .438 | 1.45142 | .463 | 1.49842 | .488 | 1.54696 |
| .414 | 1.40788 | .439 | 1.45327 | .464 | 1.50033 | .489 | 1.54893 |
| .415 | 1.40966 | .440 | 1.45512 | .465 | 1.50224 | .490 | 1.55090 |
| .416 | 1.41145 | .441 | 1.45697 | .466 | 1.50416 | .491 | 1.55288 |
| .417 | 1.41324 | .442 | 1.45883 | .467 | 1.50608 | .492 | 1.55486 |
| .418 | 1.41503 | .443 | 1.46069 | .468 | 1.50800 | .493 | 1.55685 |
| .419 | 1.41682 | .444 | 1.46255 | .469 | 1.50992 | .494 | 1.55854 |
| .420 | 1.41861 | .445 | 1.46441 | .470 | 1.51185 | .495 | 1.56083 |
| .421 | 1.42041 | .446 | 1.46628 | .471 | 1.51378 | .496 | 1.56282 |
| .422 | 1.42222 | .447 | 1.46815 | .472 | 1.51571 | .497 | 1.56481 |
| .423 | 1.42402 | .448 | 1.47002 | .473 | 1.51764 | .498 | 1.56680 |
| .424 | 1.42583 | .449 | 1.47189 | .474 | 1.51958 | .499 | 1.56879 |
| .425 | 1.42764 | .450 | 1.47377 | .475 | 1.52152 | .500 | 1.57079 |

## AREAS OF CIRCULAR SEGMENTS

The areas of circular segments are given, in proportional superficial measure, the diameter of the circle of which the segment forms a portion being = 1. The height of the segment, expressed decimally in proportion to the diameter, is given in the first column, and the relative area in the second column.

To use the table, divide the height by the diameter, find the quotient in the table, and multiply the corresponding area by the square of the actual length of the diameter; the product will be the actual area.

AREAS OF CIRCULAR SEGMENTS, UP TO A SEMICIRCLE

Diameter of Circle = 1

| Height | Area | Height | Area | Height | Area | Height | Area |
|---|---|---|---|---|---|---|---|
| .001 | .00004 | .006 | .00062 | .011 | .00153 | .016 | .00268 |
| .002 | .00012 | .007 | .00078 | .012 | .00175 | .017 | .00294 |
| .003 | .00022 | .008 | .00095 | .013 | .00197 | .018 | .00320 |
| .004 | .00034 | .009 | .00114 | .014 | .00220 | .019 | .00347 |
| .005 | .00047 | .010 | .00133 | .015 | .00244 | .020 | .00375 |

Areas of Circular Segments—(*Cont.*)

| Height | Area | Height | Area | Height | Area | Height | Area |
|---|---|---|---|---|---|---|---|
| .021 | .00403 | .066 | .02215 | .111 | .04763 | .156 | .07819 |
| .022 | .00432 | .067 | .02265 | .112 | .04826 | .157 | .07892 |
| .023 | .00461 | .068 | .02315 | .113 | .04889 | .158 | .07965 |
| .024 | .00492 | .069 | .02366 | .114 | .04953 | .159 | .08038 |
| .025 | .00523 | .070 | .02417 | .115 | .05016 | .160 | .08111 |
| .026 | .00555 | .071 | .02468 | .116 | .05080 | .161 | .08185 |
| .027 | .00587 | .072 | .02520 | .117 | .05145 | .162 | .08258 |
| .028 | .00619 | .073 | .02571 | .118 | .05209 | .163 | .08332 |
| .029 | .00653 | .074 | .02624 | .119 | .05274 | .164 | .08406 |
| .030 | .00687 | .075 | .02676 | .120 | .05338 | .165 | .08480 |
| .031 | .00721 | .076 | .02729 | .121 | .05404 | .166 | .08554 |
| .032 | .00756 | .077 | .02782 | .122 | .05469 | .167 | .08629 |
| .033 | .00792 | .078 | .02836 | .123 | .05535 | .168 | .08704 |
| .034 | .00828 | .079 | .02889 | .124 | .05600 | .169 | .08778 |
| .035 | .00864 | .080 | .02943 | .125 | .05666 | .170 | .08854 |
| .036 | .00901 | .081 | .02997 | .126 | .05733 | .171 | .08929 |
| .037 | .00939 | .082 | .03053 | .127 | .05799 | .172 | .09004 |
| .038 | .00977 | .083 | .03108 | .128 | .05866 | .173 | .09080 |
| .039 | .01015 | .084 | .03163 | .129 | .05933 | .174 | .09155 |
| .040 | .01054 | .085 | .03219 | .130 | .06000 | .175 | .09231 |
| .041 | .01093 | .086 | .03275 | .131 | .06067 | .176 | .09307 |
| .042 | .01133 | .087 | .03331 | .132 | .06135 | .177 | .09383 |
| .043 | .01173 | .088 | .03385 | .133 | .06203 | .178 | .09460 |
| .044 | .01214 | .089 | .03444 | .134 | .06271 | .179 | .09537 |
| .045 | .01255 | .090 | .03501 | .135 | .06339 | .180 | .09613 |
| .046 | .01297 | .091 | .03538 | .136 | .06407 | .181 | .09690 |
| .047 | .01340 | .092 | .03616 | .137 | .06476 | .182 | .09767 |
| .048 | .01382 | .093 | .03674 | .138 | .06545 | .183 | .09845 |
| .049 | .01425 | .094 | .03732 | .139 | .06614 | .184 | .09922 |
| .050 | .01468 | .095 | .03790 | .140 | .06683 | .185 | .10000 |
| .051 | .01512 | .096 | .03850 | .141 | .06753 | .186 | .10077 |
| .052 | .01556 | .097 | .03909 | .142 | .06822 | .187 | .10153 |
| .053 | .01601 | .098 | .03968 | .143 | .06892 | .188 | .10233 |
| .054 | .01646 | .099 | .04028 | .144 | .06963 | .189 | .10317 |
| .055 | .01691 | .100 | .04087 | .145 | .07033 | .190 | .10390 |
| .056 | .01737 | .101 | .04148 | .146 | .07103 | .191 | .10469 |
| .057 | .01783 | .102 | .04208 | .147 | .07174 | .192 | .10547 |
| .058 | .01830 | .103 | .04269 | .148 | .07245 | .193 | .10626 |
| .059 | .01877 | .104 | .04330 | .149 | .07316 | .194 | .10705 |
| .060 | .01924 | .105 | .04391 | .150 | .07387 | .195 | .10784 |
| .061 | .01972 | .106 | .04452 | .151 | .07459 | .196 | .10864 |
| .062 | .02020 | .107 | .04514 | .152 | .07530 | .197 | .10943 |
| .063 | .02068 | .108 | .04576 | .153 | .07603 | .198 | .11023 |
| .064 | .02117 | .109 | .04638 | .154 | .07675 | .199 | .11102 |
| .065 | .02166 | .110 | .04701 | .155 | .07747 | .200 | .11182 |

AREAS OF CIRCULAR SEGMENTS—(*Cont.*)

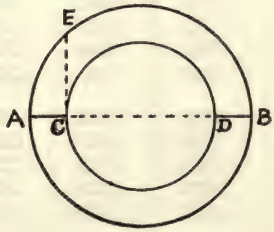
| Height | Area | Height | Area | Height | Area | Height | Area |
|---|---|---|---|---|---|---|---|
| .201 | .11262 | .246 | .15009 | .291 | .18996 | .336 | .23169 |
| .202 | .11343 | .247 | .15096 | .292 | .19086 | .337 | .23263 |
| .203 | .11423 | .248 | .15182 | .293 | .19177 | .338 | .23358 |
| .204 | .11504 | .249 | .15268 | .294 | .19268 | .339 | .23453 |
| .205 | .11584 | .250 | .15355 | .295 | .19360 | .340 | .23547 |
| .206 | .11665 | .251 | .15442 | .296 | .19451 | .341 | .23642 |
| .207 | .11746 | .252 | .15528 | .297 | .19543 | .342 | .23737 |
| .208 | .11827 | .253 | .15615 | .298 | .19634 | .343 | .23832 |
| .209 | .11908 | .254 | .15702 | .299 | .19725 | .344 | .23927 |
| .210 | .11990 | .255 | .15789 | .300 | .19817 | .345 | .24025 |
| .211 | .12071 | .256 | .15876 | .301 | .19908 | .346 | .24117 |
| .212 | .12153 | .257 | .15964 | .302 | .20000 | .347 | .24212 |
| .213 | .12235 | .258 | .16051 | .303 | .20092 | .348 | .24307 |
| .214 | .12317 | .259 | .16139 | .304 | .20184 | .349 | .24403 |
| .215 | .12399 | .260 | .16226 | .305 | .20276 | .350 | .24498 |
| .216 | .12481 | .261 | .16314 | .306 | .20368 | .351 | .24593 |
| .217 | .12563 | .262 | .16402 | .307 | .20460 | .352 | .24689 |
| .218 | .12646 | .263 | .16490 | .308 | .20553 | .353 | .24784 |
| .219 | .12729 | .264 | .16578 | .309 | .20645 | .354 | .24880 |
| .220 | .12811 | .265 | .16666 | .310 | .20738 | .355 | .24976 |
| .221 | .12894 | .266 | .16755 | .311 | .20830 | .356 | .25071 |
| .222 | .12977 | .267 | .16843 | .312 | .20923 | .357 | .25167 |
| .223 | .13060 | .268 | .16932 | .313 | .21015 | .358 | .25263 |
| .224 | .13144 | .269 | .17020 | .314 | .21108 | .359 | .25359 |
| .225 | .13227 | .270 | .17109 | .315 | .21201 | .360 | .25455 |
| .226 | .13311 | .271 | .17198 | .316 | .21294 | .361 | .25551 |
| .227 | .13395 | .272 | .17287 | .317 | .21387 | .362 | .25647 |
| .228 | .13478 | .273 | .17376 | .318 | .21480 | .363 | .25743 |
| .229 | .13562 | .274 | .17465 | .319 | .21573 | .364 | .25839 |
| .230 | .13646 | .275 | .17554 | .320 | .21667 | .365 | .25936 |
| .231 | .13731 | .276 | .17644 | .321 | .21760 | .366 | .26032 |
| .232 | .13815 | .277 | .17733 | .322 | .21853 | .367 | .26128 |
| .233 | .13899 | .278 | .17823 | .323 | .21947 | .368 | .26225 |
| .234 | .13984 | .279 | .17912 | .324 | .22040 | .369 | .26321 |
| .235 | .14069 | .280 | .18002 | .325 | .22134 | .370 | .26418 |
| .236 | .14154 | .281 | .18092 | .326 | .22228 | .371 | .26514 |
| .237 | .14239 | .282 | .18182 | .327 | .22322 | .372 | .26611 |
| .238 | .14324 | .283 | .18272 | .328 | .22415 | .373 | .26708 |
| .239 | .14409 | .284 | .18362 | .329 | .22509 | .374 | .26805 |
| .240 | .14494 | .285 | .18452 | .330 | .22603 | .375 | .26901 |
| .241 | .14580 | .286 | .18542 | .331 | .22697 | .376 | .26998 |
| .242 | .14665 | .287 | .18633 | .332 | .22792 | .377 | .27095 |
| .243 | .14752 | .288 | .18723 | .333 | .22886 | .378 | .27192 |
| .244 | .14837 | .289 | .18814 | .334 | .22980 | .379 | .27289 |
| .245 | .14923 | .290 | .18905 | .335 | .23074 | .380 | .27386 |

Areas of Circular Segments—(*Cont.*)

| Height | Area | Height | Area | Height | Area | Height | Area |
|---|---|---|---|---|---|---|---|
| .381 | .27483 | .406 | .29926 | .431 | .32392 | .462 | .35474 |
| .382 | .27580 | .407 | .30024 | .432 | .32491 | .464 | .35673 |
| .383 | .27678 | .408 | .30122 | .433 | .32590 | .466 | .35873 |
| .384 | .27775 | .409 | .30220 | .434 | .32689 | .468 | .36072 |
| .385 | .27872 | .410 | .30319 | .435 | .32788 | .470 | .36272 |
| .386 | .27969 | .411 | .30417 | .436 | .32887 | .471 | .36371 |
| .387 | .28070 | .412 | .30516 | .437 | .32987 | .473 | .36571 |
| .388 | .28164 | .413 | .30614 | .438 | .33086 | .475 | .36771 |
| .389 | .28262 | .414 | .30712 | .439 | .33185 | .477 | .36971 |
| .390 | .28359 | .415 | .30811 | .440 | .33284 | .479 | .37170 |
| .391 | .28457 | .416 | .30910 | .441 | .33384 | .482 | .37470 |
| .392 | .28554 | .417 | .31008 | .442 | .33483 | .484 | .37670 |
| .393 | .28652 | .418 | .31107 | .443 | .33582 | .486 | .37870 |
| .394 | .28750 | .419 | .31205 | .444 | .33682 | .488 | .38070 |
| .395 | .28848 | .420 | .31304 | .445 | .33781 | .490 | .38270 |
| .396 | .28945 | .421 | .31403 | .446 | .33880 | .491 | .38370 |
| .397 | .29043 | .422 | .31502 | .447 | .33980 | .492 | .38470 |
| .398 | .29141 | .423 | .31600 | .448 | .34079 | .493 | .38570 |
| .399 | .29239 | .424 | .31699 | .449 | .34179 | .494 | .38670 |
| .400 | .29337 | .425 | .31798 | .450 | .34278 | .495 | .38770 |
| .401 | .29435 | .426 | .31897 | .451 | .34378 | .496 | .38870 |
| .402 | .29533 | .427 | .31996 | .453 | .34577 | .497 | .38970 |
| .403 | .29631 | .428 | .32095 | .455 | .34776 | .498 | .39070 |
| .404 | .29729 | .429 | .32194 | .457 | .34975 | .499 | .39170 |
| .405 | .29827 | .430 | .32293 | .459 | .35175 | .500 | .39270 |

**To Find the Area of a Ring Included Between the Circumferences of Two Concentric Circles.**—Rule 1. The difference between the areas of two circles will be the area of the ring.

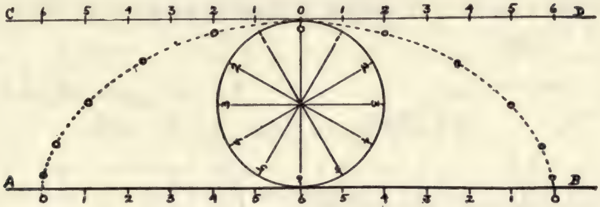
Or, multiply the sum of the diameters by their difference, and by .7854.




Rule 2. Multiply half the sum of the circumferences by half the difference of the diameter, and the product will be the area.

This rule will also serve for any part of the ring, using half the sum of the intercepted arc for half the sum of the circumference.

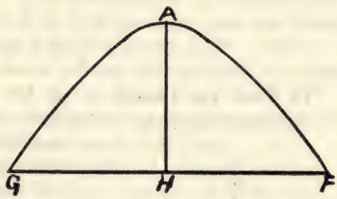
**To Find the Length of the Whole Arc of a Cycloid.**—Rule: Multiply the diameter of the generating circle by 4.



**To Find the Area of a Cycloid.**—Rule: Multiply the area of the generating circle by 3.

**To Find the Area of a Parabola.**—Rule: Multiply the base by the height; two-thirds of the product is the area.

**To Find the Length of an Arc of a Parabola,** cut off by a double ordinate to the axis. Rule: To the square of the ordinate add four-fifths of the square of the abscissa; twice the square root of the sum is the length nearly.



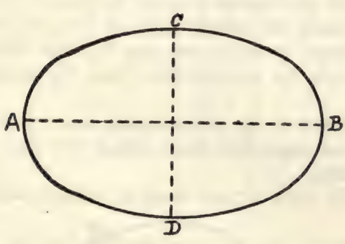
NOTE.—This rule is an approximation which applies to those cases only in which the abscissa does not exceed half the ordinate.

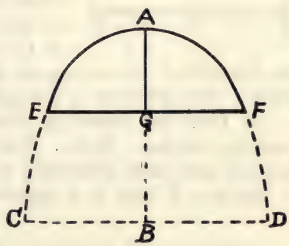
**To Find the Circumference of an Ellipse.**—Multiply the square root of half the sum of the squares of the two axes by 3.1416.

**To Find the Area of an Ellipse.**—Multiply the product of the two axes by .7854.

NOTE.—The area of an ellipse is equal to the area of a circle of which the diameter is a mean proportional between the two axes.

**To Find the Area of an Elliptic Segment,** the base of which is parallel to either axis of the ellipse. Rule: Divide the height of the segment by the axis of which it is a part, and find the area of a circular segment as given in the table relating to circular




segments, of which the height is equal to this quotient; multiply the area thus found by the two axes of the ellipse successively; the product is the area.

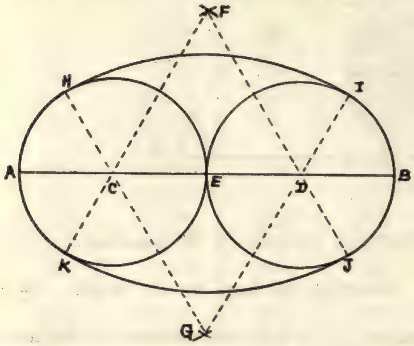
**To Describe an Elliptic Figure, When One Diameter A B is given:**

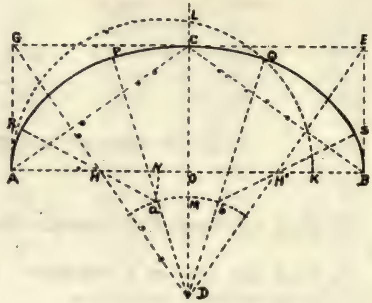
Divide A B into four equal parts. From C and D, with radius C A, or D B, describe circles touching each other in E. From C and D, with radius C D, describe arcs cutting each other in F G.

Draw lines G C, G D, F C, F D, and produce them until they cut the circles in H I J and K.

From F and G, with radius F K or G I, draw arcs uniting H with I and J with K, which will complete the figure.

**To Describe an Ellipse with Arcs of Three Radii.**—On the transverse axis A B draw the rectangle B G, on the height O C; to the diagonal A C draw the perpendicular G H D; set off O K equal to O C, and describe a semi-circle on A K, and produce O C to L; set off O M equal to C L, and on D describe an arc with radius D M; on A,

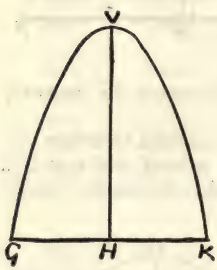


with radius O L, cut this arc at *a*. Thus the five centers D, *a*, *b*, H, H′ are found, from which the arcs are described to form the ellipse.

Note.—This process works well for nearly all proportions of ellipses. It is employed in striking out vaults, stone bridges, etc.

**To Find the Length of an Arc of a Hyperbola,** beginning at the vertex. Rule 1. To nineteen times the transverse axis add twenty-one times the parameter to this axis, and multiply the sum by the quotient of the abscissa divided by the transverse.



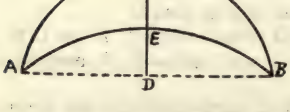

2. To nine times the transverse add twenty-one times the parameter, and multiply the sum by the quotient of the abscissa divided by the transverse.

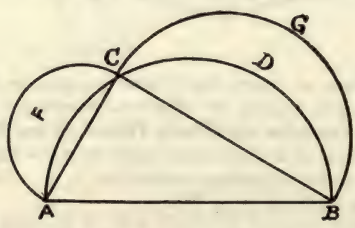
3. To each of these products add fifteen times the parameter and then, as the latter sum : is to the former sum :: so is the ordinate : to the length of the arc, nearly.

**To Find the Area of a Hyperbola.**—Rule: To the product of the transverse and abscissa add five-sevenths of the square of the abscissa, and multiply the square root of the sum by 21; to this product add four times the square root of the product of the transverse and abscissa; multiply the sum by four times the product of the conjugate and abscissa, and divide by seventy-five times the transverse. The quotient is the area nearly.

**To Find the Areas of Lunes,** or the spaces between the intersecting arcs of two eccentric circles. Rule: Find the areas of the two segments from which the lune is formed, and their difference will be the area required.

Note.—A lune is a space included between the arcs of two unequal circles inter-




secting each other in two points, and having their centers on the same side of the straight line which joins these points of intersection.

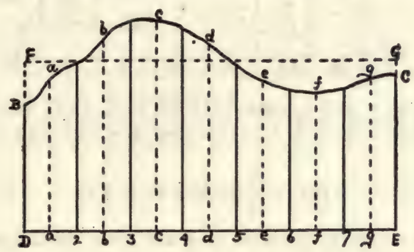
The lune was the first curvilinear space that was shown to be exactly equal to a

rectilinear one, and this was first effected by Hippocrates. The following property is one of the most curious:

If A B C be a right-angled triangle, and semicircles be described on the three sides as diameters, then will the said triangle be equal to the two lunes D and F taken together. For the semicircles described on A C and B C = the one described on A B, from each take the segments cut off by A C and B C, then will the lune A F C E and B D C G = the triangle A C B.

## AREA OF AN IRREGULAR FIGURE

The area of an irregular figure, as D E C B, in which the base is a straight line, and the perpendiculars at D and E also straight lines, the line B C, being an irregular

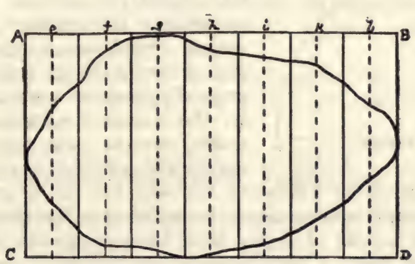



line, may be obtained by dividing the base line into a number of equal parts as indicated by full lines, and erecting an ordinate in each as shown by dotted lines.

The length of each ordinate is to be carefully measured and all are added together; the sum so obtained is divided by the number of ordinates; the quotient is the mean height, D F. Draw F G parallel to D E. Produce D B to F, and E C to G.

The parallelogram D E F G is equal in area to the irregular figure: then Area = Base × Height.

**Case 2. A Non-Symmetrical Figure.**—When the area is not symmetrical about a




line, the figure should be enclosed by drawing a base line and erecting perpendiculars, each touching the projecting curves at that side.

Draw A B parallel to C D; this line must also touch the highest curve at the top of the figure. The parallelogram A B C D is thus formed around the figure.

The base C D is to be divided into any number of equal parts, and in the center of each draw ordinates, *e f g h*, etc.

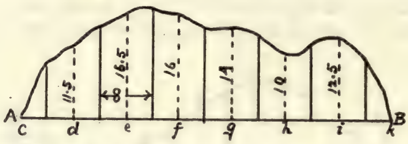
Measure the ordinates, add them together, and divide the sum by the number of ordinates, the quotient will be the equivalent height for a parallelogram of which the base is C D.

**Simpson's Rule.**—Divide the base line A B into a number of equal parts. This ensures that the number of ordinates is an odd number. Draw the ordinates from the base line to the boundary line.

Add together the first and last ordinates and call the sum A.
Add together the even ordinates and call that sum B.
Add together the odd ordinates, except the first and last, and call the sum C.
Let D be the common distance, then

$$\frac{A + 4\,B + 2\,C \times D}{3} = \text{Area of Figure.}$$

Rule: Add together the extreme ordinates, four times the sum of the even ordinates, and twice the sum of the odd ordinates (omitting the first and the last). Multiply the result by one-third the common interval between the consecutive ordinates.



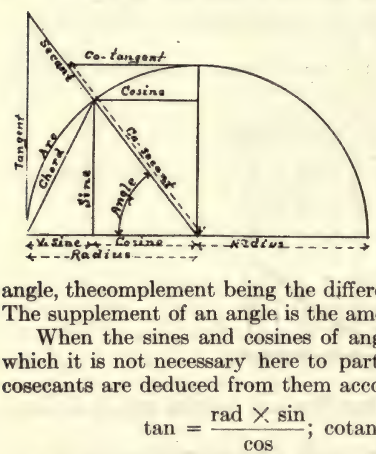

The end ordinates, as *c* and *k*, may both be zero, as in the illustration, the curve commencing from the base line A B. In this case A is zero, and the above rule expressed as formula becomes,

$$\text{Area} = \frac{S}{3}\,(O + 4\,B = 2\,C),$$

in which S denotes the common distance or space between the ordinates.

## PLANE TRIGONOMETRY

The circumference of a circle is supposed to be divided into 360° or divisions, and as the total angularity about the center is equal to four right angles, each right angle contains 90 degrees, or 90°, and half a right angle contains 45°. Each degree is divided into 60 minutes, or 60′; and, for the sake of still further minuteness of measurement, each minute is divided into 60 seconds, or 60″. In a whole circle there are, therefore, 360 × 60 × 60 = 1,296,000 seconds. The annexed diagram exemplifies the relative positions of the sine, cosine, versed sine, tangent, cotangent, secant, and cosecant of an angle. It may be stated, generally, that the correlated quantities, namely, the cosine, cotangent, and cosecant of an angle, are the sine, tangent, and secant, respectively, of the complement of the given angle, thecomplement being the difference between the given angle and a right angle. The supplement of an angle is the amount by which it is less than two right angles.




When the sines and cosines of angles have been calculated (by means of formulæ which it is not necessary here to particularize) the tangents, cotangents, secants, and cosecants are deduced from them according to the following relations:

$$\tan = \frac{\text{rad} \times \sin}{\cos};\ \text{cotan} = \frac{\text{rad}^2}{\tan};\ \sec = \frac{\text{rad}^2}{\cos};\ \text{cosec} = \frac{\text{rad}^2}{\sin}.$$

For these the values will be amplified in tabular form.

A triangle consists of three sides and three angles. When any three of these are given, including a side, the other three may be found by calculation:

Case 1.—*When a side and its opposite angle are two of the given parts.*

Rule 1. *To find a side*, work the following proportion:

as the sine of the angle opposite the given side
is to the sine of the angle opposite the required side,
so is the given side
to the required side.

Rule 2. *To find an angle:*

as the side opposite to the given angle
is to the side opposite to the required angle,
so is the sine of the given angle
to the sine of the required angle.

Rule 3. *In a right-angled triangle, when the angues and one side next the right angle are given, to find the other side:*

as radius
is to the tangent of the angle adjacent to the given side,
so is this side
to the other side.

Case 2.—*When two sides and the included angle are given.*

Rule 4. *To find the other side:*

as the sum of the two given sides
is to their difference,
so is the tangent of half the sum of their opposite angles
to the tangent of half their difference—

add this half difference to the half sum to find the greater angle, and subtract the half difference from the half sum to find the less angle. The other side may then be found by Rule 1.

Rule 5. *When the sides of a right-angled triangle are given, to find the angles:*

as one side
is to the other side,
so is the radius
to the tangent of the angle adjacent to the first side.

Case 3.—*When the three sides are given.*

Rule 6. *To find an angle.*—Subtract the sum of the logarithms of the sides which contain the required angle from 20, and to the remainder add the logarithm of half the sum of the three sides, and that of the difference between this half sum and the side opposite to the required angle. Half the sum of these three logarithms will be the logarithmic cosine of half the required angle. The other angles may be found by Rule 1.

Rule 7. Subtract the sum of the logarithms of the two sides which contain the required angle from 20, and to the remainder add the logarithms of the differences between these two sides and half the sum of the three sides. Half the result will be the logarithmic sine of half the required angle.

NOTE.—In all ordinary cases either of these rules gives sufficiently accurate results. It is recommended that Rule 6 should be used when the required angle exceeds 90°; and Rule 7 when it is less than 90°.

## TRIGONOMETRICAL FORMULÆ

The diagram shows the different trigonometrical expressions in terms of the angle A. In the following formulæ Radius = 1.

Complement of an angle = its difference from 90°.

Supplement of an angle = its difference from 180°.

$$\sin = \frac{1}{\text{cosec}} = \frac{\cos}{\cot} = \sqrt{(1 - \cos^2)}$$

$$\tan = \frac{\sin}{\cos} = \frac{1}{\cot}$$

$$\sec = \sqrt{\text{rad}^2 + \tan^2} = \frac{1}{\cos} = \frac{\tan}{\sin}$$

$$\cos = \sqrt{(1 - \sin^2)} = \frac{\sin}{\tan} = \sin \times \cot = \frac{1}{\sec}$$

$$\cot = \frac{\cos}{\sin} = \frac{1}{\tan}. \qquad \text{cosec} = \frac{1}{\sin}$$

$$\text{versin} = \text{rad} - \cos \quad \text{coversin} = \text{rad} - \sin$$
$$\text{rad} = \tan \times \cot = \sqrt{\sin^2 + \cos^2}$$

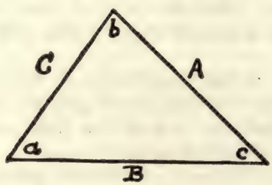
**Solution of Right-Angled Triangles.**—

$$\text{hyp}^2 = \text{base}^2 + \text{perp}^2$$
$$\text{base}^2 = (\text{hyp} + \text{perp}) \times (\text{hyp} - \text{perp})$$
$$\text{perp}^2 = (\text{hyp} + \text{base}) \times (\text{hyp} - \text{base})$$

$$\sin = a\frac{A}{C} \qquad \cot a = \frac{B}{A}$$
$$\cos a = \frac{B}{C} \qquad \cos b = \frac{A}{C}$$
$$\tan a = \frac{A}{B} \qquad \cot b = \frac{A}{B}$$
$$\text{cosec } a = \frac{C}{A} \qquad b = 90° - a$$
$$A = B \tan a$$
$$\sec a = \frac{C}{B} \qquad A = C \sin a$$

$$B = C \cos a = A \cot a = \sqrt{(C + A)(C - A)}$$
$$C = \sqrt{A^2 + B^2} = \frac{A}{\sin a} = \frac{B}{\cos a}$$

**Solution of Oblique-Angled Triangles.**—Value of any side C is:




$$C = \frac{A \sin c}{\sin a} = \frac{B \sin c}{\sin b} = \frac{A}{\cos b + \sin b \cot c}$$
$$C = \frac{B}{\cos a + \sin a \cot c} = A \cos b + A$$
$$C = \sqrt{A^2 + B^2 - 2\,A\,B \cos c} = B \cos a + B \sin a \cot b$$

Value of any angle *a* is:

$$\sin a = \frac{A \sin c}{c} = \frac{A \sin b}{B} = \sin (b + c)$$

$$\sin a = \sin b \cos c + \cos b \sin c.$$
$$\cos a = \sin b \sin c - \cos b \cos c.$$

$$\cos a = \frac{C^2 + B^2 - A^2}{2\,B\,C}$$

$$\tan a = \frac{A \sin c}{B - A \cos c} = \frac{A \sin b}{C - A \cos b}$$

## SINES, COSINES, TANGENTS, COTANGENTS, SECANTS, AND COSECANTS OF ANGLES FROM 0° TO 90°

This table is constructed for angles of from 0° to 90°, advancing by 10′, or one-sixth of a degree. The length of the radius is equal to 1, and forms the basis for the relative lengths given in the table, and which are given to six places of decimals. Each entry in the table has a duplicate significance, being the sine, tangent, or secant of one angle, and at the same time the cosine, cotangent, or cosecant of its complement. For this reason, and for the sake of compactness, the headings of the columns are reversed at the foot; so that the upper headings are correct for the angles named in the left-hand margin of the table, and the lower headings for those named in the right-hand margin.

**To Find the Sine, or Other Element, to Odd Minutes.**—Divide the difference between the sines, etc., of the two angles greater and less than the given angle, in the same proportion that the given angle divides the difference of the two angles, and add one of the parts to the sine next it.

By an inverse process the angle may be found for any given sine, etc., not found in the table.

Sines, Cosines, Tangents, Cotangents, Secants and Cosecants for Angles 0° to 90°

Advancing by 10′ or one-sixth of a Degree. Radius = 1

| Angle | Sine | Cosecant | Tangent | Cotangent | Secant | Cosine | |
|---|---|---|---|---|---|---|---|
| 0° 0′ | .000000 | Infinite | .000000 | Infinite | 1.00000 | 1.000000 | 90° 0′ |
| 10 | .002909 | 343.77516 | .002909 | 343.77371 | 1.00000 | .999996 | 50 |
| 20 | .005818 | 171.88831 | .005818 | 171.88540 | 1.00002 | .999983 | 40 |
| 30 | .008727 | 114.59301 | .008727 | 114.58865 | 1.00004 | .999962 | 30 |
| 40 | .011635 | 85.945609 | .011636 | 85.939791 | 1.00007 | .999932 | 20 |
| 50 | .014544 | 68.757360 | .014545 | 68.750087 | 1.00011 | .999894 | 10 |
| 1° 0′ | .017452 | 57.298688 | .017455 | 57.289962 | 1.00015 | .999848 | 89° 0′ |
| 10 | .020361 | 49.114062 | .020365 | 49.103881 | 1.00021 | .999793 | 50 |
| 20 | .023269 | 42.975713 | .023275 | 42.964077 | 1.00027 | .999729 | 40 |
| 30 | .026177 | 38.201550 | .026186 | 38.188459 | 1.00034 | .999657 | 30 |
| 40 | .029085 | 34.382316 | .029097 | 34.367771 | 1.00042 | .999577 | 20 |
| 50 | .031992 | 31.257577 | .032009 | 31.241577 | 1.00051 | .999488 | 10 |
| 2° 0′ | .034899 | 28.653708 | .034921 | 28.636253 | 1.00061 | .999391 | 88° 0′ |
| 10 | .037806 | 26.450510 | .037834 | 26.431600 | 1.00072 | .999285 | 50 |
| 20 | .040713 | 24.562123 | .040747 | 24.541758 | 1.00083 | .999171 | 40 |
| 30 | .043619 | 22.925586 | .043661 | 22.903766 | 1.00095 | .999048 | 30 |
| 40 | .046525 | 21.493676 | .046576 | 21.470401 | 1.00108 | .998917 | 20 |
| 50 | .049431 | 20.230284 | .049491 | 20.205553 | 1.00122 | .998778 | 10 |
| 3° 0′ | .052336 | 19.107323 | .052408 | 19.081137 | 1.00137 | .998630 | 87° 0′ |
| 10 | .055241 | 18.102619 | .055325 | 18.074977 | 1.00153 | .998473 | 50 |
| 20 | .058145 | 17.198434 | .058243 | 17.169337 | 1.00169 | .998308 | 40 |
| 30 | .061049 | 16.380408 | .061163 | 16.349855 | 1.00187 | .998135 | 30 |
| 40 | .063952 | 15.636793 | .064083 | 15.604784 | 1.00205 | .997857 | 20 |
| 50 | .066854 | 14.957882 | .067004 | 14.924417 | 1.00224 | .997763 | 10 |
| | Cosine | Secant | Cotangent | Tangent | Cosecant | Sine | Angle |

SINES, COSINES, TANGENTS, ETC.—(*Cont.*)

| Angle | Sine | Cosecant | Tangent | Cotangent | Secant | Cosine | |
|---|---|---|---|---|---|---|---|
| 4° 0′ | .069756 | 14.335587 | .069927 | 14.300666 | 1.00244 | .997564 | 86° 0′ |
| 10 | .072658 | 13.763115 | .072851 | 13.726738 | 1.00265 | .997357 | 50 |
| 20 | .075559 | 13.234717 | .075776 | 13.196888 | 1.00287 | .997141 | 40 |
| 30 | .078459 | 12.745495 | .078702 | 12.706205 | 1.00309 | .996917 | 30 |
| 40 | .081359 | 12.291252 | .081629 | 12.2505505 | 1.00333 | .996685 | 20 |
| 50 | .084258 | 11.868370 | .084558 | 11.826167 | 1.00357 | .996444 | 10 |
| 5° 0′ | .087156 | 11.473713 | .087489 | 11.430052 | 1.00382 | .996195 | 85° 0′ |
| 10 | .090053 | 11.104549 | .090421 | 11.059431 | 1.00408 | .995937 | 50 |
| 20 | .092950 | 10.758488 | .093354 | 10.711913 | 1.00435 | .995671 | 40 |
| 30 | .095846 | 10.433431 | .096289 | 10.385397 | 1.00463 | .995396 | 30 |
| 40 | .098741 | 10.127522 | .099226 | 10.078031 | 1.00491 | .995113 | 20 |
| 50 | .101635 | 9.8391227 | .102164 | 9.7881732 | 1.00521 | .994822 | 10 |
| 6° 0′ | .104528 | 9.5667722 | .105104 | 9.5143645 | 1.00551 | .994522 | 84° 0′ |
| 10 | .107421 | 9.3091699 | .108046 | 9.2553035 | 1.00582 | .994214 | 50 |
| 20 | .110313 | 9.0651512 | .110990 | 9.0098261 | 1.00614 | .993897 | 40 |
| 30 | .113203 | 8.8336715 | .113936 | 8.7768874 | 1.00647 | .993572 | 30 |
| 40 | .116093 | 8.6137901 | .116883 | 8.5555468 | 1.00681 | .993238 | 20 |
| 50 | .118982 | 8.4045586 | .119833 | 8.3449558 | 1.00715 | .992896 | 10 |
| 7° 0′ | .121869 | 8.2055090 | .122785 | 8.1443464 | 1.00751 | .992546 | 83° 0′ |
| 10 | .124756 | 8.0156450 | .125738 | 7.9530224 | 1.00787 | .992187 | 50 |
| 20 | .127642 | 7.8344335 | .128694 | 7.7703506 | 1.00825 | .991820 | 40 |
| 30 | .130526 | 7.6612976 | .131653 | 7.5957541 | 1.00863 | .991445 | 30 |
| 40 | .133410 | 7.4957100 | .134613 | 7.4287064 | 1.00902 | .991061 | 20 |
| 50 | .136292 | 7.3371909 | .137576 | 7.2687255 | 1.00942 | .990669 | 10 |
| 8° 0′ | .139173 | 7.1852965 | .140541 | 7.1153697 | 1.00983 | .990268 | 82° 0′ |
| 10 | .142053 | 7.0396220 | .143508 | 6.9682335 | 1.01024 | .989859 | 50 |
| 20 | .144932 | 6.8997942 | .146478 | 6.8269437 | 1.01067 | .989442 | 40 |
| 30 | .147809 | 6.7654691 | .149451 | 6.6911562 | 1.01111 | .989016 | 30 |
| 40 | .150686 | 6.6363293 | .152426 | 6.5605538 | 1.01155 | .988582 | 20 |
| 50 | .153561 | 6.5120812 | .155404 | 6.4348428 | 1.01200 | .988139 | 10 |
| 9° 0′ | .156434 | 6.3924532 | .158384 | 6.3137515 | 1.01247 | .987688 | 81° 0′ |
| 10 | .159307 | 6.2771933 | .161368 | 6.1970279 | 1.01294 | .987229 | 50 |
| 20 | .162178 | 6.1660674 | .164354 | 6.0844381 | 1.01332 | .986762 | 40 |
| 30 | .165048 | 6.0588980 | .167343 | 5.9757644 | 1.01391 | .986286 | 30 |
| 40 | .167916 | 5.9553625 | .170334 | 5.8708042 | 1.01440 | .985801 | 20 |
| 50 | .170783 | 5.8553921 | .173329 | 5.7693688 | 1.01491 | .985309 | 10 |
| 10° 0′ | .173648 | 5.7587705 | .176327 | 5.6712818 | 1.01543 | .984808 | 80° 0′ |
| 10 | .176512 | 5.6653331 | .179328 | 5.5763786 | 1.01595 | .984298 | 50 |
| 20 | .179375 | 5.5749258 | .182332 | 5.4845052 | 1.01649 | .983781 | 40 |
| 30 | .182236 | 5.4874043 | .185339 | 5.3955172 | 1.01703 | .983255 | 30 |
| 40 | .185095 | 5.4026333 | .188359 | 5.3092793 | 1.01758 | .982721 | 20 |
| 50 | .187953 | 5.3204860 | .191363 | 5.2256647 | 1.01815 | .982178 | 10 |
| | Cosine | Secant | Cotangent | Tangent | Cosecant | Sine | Angle |

SINES, COSINES, TANGENTS, ETC.—(*Cont.*)

| Angle | Sine | Cosecant | Tangent | Cotangent | Secant | Cosine | |
|---|---|---|---|---|---|---|---|
| 11° 0′ | .190809 | 5.2408431 | .194380 | 5.1445540 | 1.01872 | .981627 | 79° 0′ |
| 10 | .193664 | 5.1635924 | .197401 | 5.0658352 | 1.01930 | .981068 | 50 |
| 20 | .196517 | 5.0886284 | .200425 | 4.9894027 | 1.01989 | .980500 | 40 |
| 30 | .199368 | 5.0158317 | .203452 | 4.9151570 | 1.02049 | .979925 | 30 |
| 40 | .202218 | 4.9451687 | .206483 | 4.8430045 | 1.02110 | .979341 | 20 |
| 50 | .205065 | 4.8764907 | .209518 | 4.7728568 | 1.02171 | .978748 | 10 |
| 12° 0′ | .207912 | 4.8097343 | .212557 | 4.7046301 | 1.02234 | .978148 | 78° 0′ |
| 10 | .210756 | 4.7448206 | .215599 | 4.6382457 | 1.02298 | .977539 | 50 |
| 20 | .213599 | 4.6816748 | .218645 | 4.5736287 | 1.02362 | .976921 | 40 |
| 30 | .216440 | 4.6202263 | .221695 | 4.5107085 | 1.02428 | .976296 | 30 |
| 40 | .219279 | 4.5604080 | .224748 | 4.4494181 | 1.02494 | .975662 | 20 |
| 50 | .222116 | 4.5021565 | .227806 | 4.3896940 | 1.02562 | .975020 | 10 |
| 13° 0′ | .224951 | 4.4454115 | .230868 | 4.3314759 | 1.02630 | .974370 | 77° 0′ |
| 10 | .227784 | 4.3901158 | .233934 | 4.2747066 | 1.02700 | .973712 | 50 |
| 20 | .230616 | 4.3362150 | .237004 | 4.2193318 | 1.02770 | .973045 | 40 |
| 30 | .233445 | 4.2836576 | .240079 | 4.1652998 | 1.02842 | .972370 | 30 |
| 40 | .236273 | 4.2323943 | .243158 | 4.1125614 | 1.02914 | .971687 | 20 |
| 50 | .239098 | 4.1823785 | .246241 | 4.0610700 | 1.02987 | .970995 | 10 |
| 14° 0′ | .241922 | 4.1335655 | .249328 | 4.0107809 | 1.03061 | .970296 | 76° 0′ |
| 10 | .244743 | 4.0859130 | .252420 | 3.9616518 | 1.03137 | .969588 | 50 |
| 20 | .247563 | 4.0393804 | .255517 | 3.9136420 | 1.03213 | .968872 | 40 |
| 30 | .250380 | 3.9939292 | .258618 | 3.8667131 | 1.03290 | .968148 | 30 |
| 40 | .253195 | 3.9495224 | .261723 | 3.8208281 | 1.03363 | .967415 | 20 |
| 50 | .256008 | 3.9061250 | .264834 | 3.7759519 | 1.03447 | .966675 | 10 |
| 15° 0′ | .258819 | 3.8637033 | .267949 | 3.7320508 | 1.03528 | .965926 | 75° 0′ |
| 10 | .261628 | 3.8222251 | .271069 | 3.6890927 | 1.03609 | .965169 | 50 |
| 20 | .264434 | 3.7816596 | .274195 | 3.6470467 | 1.03691 | .964404 | 40 |
| 30 | .267238 | 3.7419775 | .277325 | 3.6058835 | 1.03774 | .963630 | 30 |
| 40 | .270040 | 3.7031506 | .280460 | 3.5655749 | 1.03858 | .962849 | 20 |
| 50 | .272840 | 3.6651518 | .283600 | 3.5260938 | 1.03944 | .962059 | 10 |
| 16° 0′ | .275637 | 3.6279553 | .286745 | 3.4874144 | 1.04030 | .961262 | 74° 0′ |
| 10 | .278432 | 3.5915363 | .289896 | 3.4495120 | 1.04117 | .960456 | 50 |
| 20 | .281225 | 3.5558710 | .293052 | 3.4123626 | 1.04206 | .959642 | 40 |
| 30 | .284015 | 3.5209365 | .296214 | 3.3759434 | 1.04295 | .958820 | 30 |
| 40 | .286803 | 3.4867110 | .299380 | 3.3402326 | 1.04385 | .957990 | 20 |
| 50 | .289589 | 3.4531735 | .302553 | 3.3052091 | 1.04477 | .957151 | 10 |
| 17° 0′ | .292372 | 3.4203036 | .305731 | 3.2708526 | 1.04569 | .956305 | 73° 0′ |
| 10 | .295152 | 3.3880820 | .308914 | 3.2371438 | 1.04663 | .955450 | 50 |
| 20 | .297930 | 3.3564900 | .312104 | 3.2040638 | 1.04757 | .954588 | 40 |
| 30 | .300706 | 3.3255095 | .315299 | 3.1715948 | 1.04853 | .953717 | 30 |
| 40 | .303479 | 3.2951234 | .318500 | 3.1397194 | 1.04950 | .952838 | 20 |
| 50 | .306249 | 3.2653149 | .321707 | 3.1084210 | 1.05047 | .951951 | 10 |
| | Cosine | Secant | Cotangent | Tangent | Cosecant | Sine | Angle |

SINES, COSINES, TANGENTS, ETC.—(*Cont.*)

| Angle | Sine | Cosecant | Tangent | Cotangent | Secant | Cosine | |
|---|---|---|---|---|---|---|---|
| 18° 0′ | .309017 | 3.2360680 | .324920 | 3.0776835 | 1.05146 | .951057 | 72° 0′ |
| 10 | .311782 | 3.2073673 | .328139 | 3.0474915 | 1.05246 | .950154 | 50 |
| 20 | .314545 | 3.1791978 | .331364 | 3.0178301 | 1.05347 | .949243 | 40 |
| 30 | .317305 | 3.1515453 | .334595 | 2.9886850 | 1.05449 | .948324 | 30 |
| 40 | .320062 | 3.1243959 | .337833 | 2.9600422 | 1.05552 | .947397 | 20 |
| 50 | .322816 | 3.0977363 | .341077 | 2.9318885 | 1.05657 | .946462 | 10 |
| 19° 0′ | .325568 | 3.0715535 | .344328 | 2.9042109 | 1.05762 | .945519 | 71° 0′ |
| 10 | .328317 | 3.0458352 | .347585 | 2.8769970 | 1.05869 | .944568 | 50 |
| 20 | .331063 | 3.0205693 | .350848 | 2.8502349 | 1.05976 | .943609 | 40 |
| 30 | .333807 | 2.9957443 | .354119 | 2.8239129 | 1.06085 | .942641 | 30 |
| 40 | .336547 | 2.9713490 | .357396 | 2.7980198 | 1.06195 | .941666 | 20 |
| 50 | .339285 | 2.9473724 | .360680 | 2.7725448 | 1.06306 | .940684 | 10 |
| 20° 0′ | .342020 | 2.9238044 | .363970 | 2.7474774 | 1.06418 | .939693 | 70° 0′ |
| 10 | .344752 | 2.9006346 | .367268 | 2.7228076 | 1.06531 | .938694 | 50 |
| 20 | .347481 | 2.8778532 | .370573 | 2.6985254 | 1.06645 | .937687 | 40 |
| 30 | .350207 | 2.8554510 | .373885 | 2.6746215 | 1.06761 | .936672 | 30 |
| 40 | .352931 | 2.8334185 | .377204 | 2.6510867 | 1.06878 | .935650 | 20 |
| 50 | .355651 | 2.8117471 | .380530 | 2.6279121 | 1.06995 | .934619 | 10 |
| 21° 0′ | .358368 | 2.7904281 | .383864 | 2.6050891 | 1.07115 | .933580 | 69° 0′ |
| 10 | .361082 | 2.7694532 | .387205 | 2.5826094 | 1.07235 | .932534 | 50 |
| 20 | .363793 | 2.7488144 | .390554 | 2.5604649 | 1.07356 | .931480 | 40 |
| 30 | .366501 | 2.7285038 | .393911 | 2.5386479 | 1.07479 | .930418 | 30 |
| 40 | .369206 | 2.7085139 | .397275 | 2.5171507 | 1.07602 | .929348 | 20 |
| 50 | .371908 | 2.6888374 | .400647 | 2.4959661 | 1.07727 | .928270 | 10 |
| 22° 0′ | .374607 | 2.6694672 | .404026 | 2.4750869 | 1.07853 | .927184 | 68° 0′ |
| 10 | .377302 | 2.6503962 | .407414 | 2.4545061 | 1.07981 | .926090 | 50 |
| 20 | .379994 | 2.6316180 | .410810 | 2.4342172 | 1.08109 | .924989 | 40 |
| 30 | .382683 | 2.6131259 | .414214 | 2.4142136 | 1.08239 | .923880 | 30 |
| 40 | .385369 | 2.5949137 | .417626 | 2.3944889 | 1.08370 | .922762 | 20 |
| 50 | .388052 | 2.5769753 | .421046 | 2.3750372 | 1.08503 | .921638 | 10 |
| 23° 0′ | .390731 | 2.5593047 | .424475 | 2.3558524 | 1.08636 | .920505 | 67° 0′ |
| 10 | .393407 | 2.5418961 | .427912 | 2.3369287 | 1.08771 | .919364 | 50 |
| 20 | .396080 | 2.5247440 | .431358 | 2.3182606 | 1.08907 | .918216 | 40 |
| 30 | .398749 | 2.5078428 | .434812 | 2.2998425 | 1.09044 | .917060 | 30 |
| 40 | .401415 | 2.4911874 | .438276 | 2.2816693 | 1.09183 | .915896 | 20 |
| 50 | .404078 | 2.4747726 | .441748 | 2.2637357 | 1.09323 | .914725 | 10 |
| 24° 0′ | .406737 | 2.4585933 | .445229 | 2.2460368 | 1.09464 | .913545 | 66° 0′ |
| 10 | .409392 | 2.4426448 | .448719 | 2.2285676 | 1.09606 | .912358 | 50 |
| 20 | .412045 | 2.4269222 | .452218 | 2.2113234 | 1.09750 | .911164 | 40 |
| 30 | .414693 | 2.4114210 | .455726 | 2.1942997 | 1.09895 | .909961 | 30 |
| 40 | .417338 | 2.3961367 | .459244 | 2.1774920 | 1.10041 | .908751 | 20 |
| 50 | .419980 | 2.3810650 | .462771 | 2.1608958 | 1.10189 | .907533 | 10 |
| | Cosine | Secant | Cotangent | Tangent | Cosecant | Sine | Angle |

SINES, COSINES, TANGENTS, ETC.—(*Cont.*)

| Angle | Sine | Cosecant | Tangent | Cotangent | Secant | Cosine | |
|---|---|---|---|---|---|---|---|
| 25° 0′ | .422618 | 2.3662016 | .466308 | 2.1445069 | 1.10338 | .906308 | 65° 0′ |
| 10 | .425253 | 2.3515424 | .469854 | 2.1283213 | 1.10488 | .905075 | 50 |
| 20 | .427884 | 2.3370833 | .473410 | 2.1123348 | 1.10640 | .903834 | 40 |
| 30 | .430511 | 2.3228205 | .476976 | 2.0965436 | 1.10793 | .902585 | 30 |
| 40 | .433135 | 2.3087501 | .480551 | 2.0809438 | 1.10947 | .901329 | 20 |
| 50 | .435755 | 2.2948685 | .484137 | 2.0655318 | 1.11103 | .900065 | 10 |
| 26° 0′ | .438371 | 2.2811720 | .487733 | 2.0503038 | 1.11260 | .898794 | 64° 0′ |
| 10 | .440984 | 2.2676571 | .491339 | 2.0352565 | 1.11419 | .897515 | 50 |
| 20 | .443593 | 2.2543204 | .494955 | 2.0203862 | 1.11579 | .896229 | 40 |
| 30 | .446198 | 2.2411585 | .498582 | 2.0056897 | 1.11740 | .894934 | 30 |
| 40 | .448799 | 2.2281681 | .502219 | 1.9911637 | 1.11903 | .893633 | 20 |
| 50 | .451397 | 2.2153460 | .505867 | 1.9768050 | 1.12067 | .892323 | 10 |
| 27° 0′ | .453990 | 2.2026893 | .509525 | 1.9626105 | 1.12233 | .891007 | 63° 0′ |
| 10 | .456580 | 2.1901947 | .513195 | 1.9485772 | 1.12400 | .889682 | 50 |
| 20 | .459166 | 2.1778595 | .516876 | 1.9347020 | 1.12568 | .888350 | 40 |
| 30 | .461749 | 2.1656806 | .520567 | 1.9209821 | 1.12738 | .887011 | 30 |
| 40 | .464327 | 2.1536553 | .524270 | 1.9074147 | 1.12910 | .885664 | 20 |
| 50 | .466901 | 2.1417808 | .527984 | 1.8939971 | 1.13083 | .884309 | 10 |
| 28° 0′ | .469472 | 2.1300545 | .531709 | 1.8807265 | 1.13257 | .882948 | 62° 0′ |
| 10 | .472038 | 2.1184737 | .535547 | 1.8676003 | 1.13433 | .881578 | 50 |
| 20 | .474600 | 2.1070359 | .539195 | 1.8546159 | 1.13610 | .880201 | 40 |
| 30 | .477159 | 2.0957385 | .542956 | 1.8417409 | 1.13789 | .878817 | 30 |
| 40 | .479713 | 2.0845792 | .546728 | 1.8290628 | 1.13970 | .877425 | 20 |
| 50 | .482263 | 2.0735556 | .550515 | 1.8164892 | 1.14152 | .876026 | 10 |
| 29° 0′ | .484810 | 2.0626653 | .554309 | 1.8040478 | 1.14335 | .874620 | 61° 0′ |
| 10 | .487352 | 2.0519061 | .558118 | 1.7917362 | 1.14521 | .873206 | 50 |
| 20 | .489890 | 2.0412757 | .561939 | 1.7795524 | 1.14707 | .871784 | 40 |
| 30 | .492424 | 2.0307720 | .565773 | 1.7674940 | 1.14896 | .870356 | 30 |
| 40 | .494953 | 2.0203929 | .569619 | 1.7555590 | 1.15085 | .868920 | 20 |
| 50 | .497479 | 2.0101362 | .573478 | 1.7437453 | 1.15277 | .867476 | 10 |
| 30° 0′ | .500000 | 2.0000000 | .577350 | 1.7320508 | 1.15470 | .866025 | 60° 0′ |
| 10 | .502517 | 1.9899822 | .581235 | 1.7204736 | 1.15665 | .864567 | 50 |
| 20 | .505030 | 1.9800810 | .585134 | 1.7090116 | 1.15861 | .863102 | 40 |
| 30 | .507538 | 1.9702944 | .589045 | 1.6976631 | 1.16059 | .861629 | 30 |
| 40 | .510043 | 1.9606206 | .592970 | 1.6864261 | 1.16259 | .860149 | 20 |
| 50 | .512543 | 1.9510577 | .596908 | 1.6752988 | 1.16460 | .858662 | 10 |
| 31° 0′ | .515038 | 1.9416040 | .600861 | 1.6642795 | 1.16663 | .857167 | 59° 0′ |
| 10 | .517529 | 1.9322578 | .604827 | 1.6533663 | 1.16868 | .855665 | 50 |
| 20 | .520016 | 1.9230173 | .608807 | 1.6425576 | 1.17075 | .854156 | 40 |
| 30 | .522499 | 1.9138809 | .612801 | 1.6318517 | 1.17283 | .852640 | 30 |
| 40 | .524977 | 1.9048469 | .616809 | 1.6212469 | 1.17493 | .851117 | 20 |
| 50 | .527450 | 1.8959138 | .620832 | 1.6107417 | 1.17704 | .849586 | 10 |
| | Cosine | Secant | Cotangent | Tangent | Cosecant | Sine | Angle |

SINES, COSINES, TANGENTS, ETC.—(*Cont.*)

| Angle | Sine | Cosecant | Tangent | Cotangent | Secant | Cosine | |
|---|---|---|---|---|---|---|---|
| 32° 0′ | .529919 | 1.8870799 | .624869 | 1.6003345 | 1.17918 | .848048 | 58° 0′ |
| 10 | .532384 | 1.8783438 | .628921 | 1.5900238 | 1.18133 | .846503 | 50 |
| 20 | .534844 | 1.8697040 | .632988 | 1.5798079 | 1.18350 | .844951 | 40 |
| 30 | .537300 | 1.8611590 | .637079 | 1.5696856 | 1.18569 | .843391 | 30 |
| 40 | .539751 | 1.8527073 | .641167 | 1.5596552 | 1.18790 | .841825 | 20 |
| 50 | .542197 | 1.8443476 | .645280 | 1.5497155 | 1.19012 | .840251 | 10 |
| 33° 0′ | .544639 | 1.8360785 | .649408 | 1.5398650 | 1.19236 | .838671 | 57° 0′ |
| 10 | .547076 | 1.8278985 | .653531 | 1.5301025 | 1.19463 | .837083 | 50 |
| 20 | .549509 | 1.8198065 | .657710 | 1.5204261 | 1.19691 | .835488 | 40 |
| 30 | .551937 | 1.8118010 | .661886 | 1.5108352 | 1.19920 | .833886 | 30 |
| 40 | .554360 | 1.8038809 | .666077 | 1.5013282 | 1.20152 | .832277 | 20 |
| 50 | .556779 | 1.7960449 | .670285 | 1.4919039 | 1.20386 | .830661 | 10 |
| 34° 0′ | .559193 | 1.7882916 | .674509 | 1.4825610 | 1.20622 | .829038 | 56° 0′ |
| 10 | .561602 | 1.7806201 | .678749 | 1.4732983 | 1.20859 | .827407 | 50 |
| 20 | .564007 | 1.7730290 | .683007 | 1.4641147 | 1.21099 | .825770 | 40 |
| 30 | .566406 | 1.7655173 | .687281 | 1.4550090 | 1.21341 | .824126 | 30 |
| 40 | .568801 | 1.7580837 | .691573 | 1.4459801 | 1.21584 | .822475 | 20 |
| 50 | .571191 | 1.7507273 | .695881 | 1.4370268 | 1.21830 | .820817 | 10 |
| 35° 0′ | .573576 | 1.7434468 | .700208 | 1.4281480 | 1.22077 | .819152 | 55° 0′ |
| 10 | .575957 | 1.7362413 | .704552 | 1.4193427 | 1.22327 | .817480 | 50 |
| 20 | .578332 | 1.7291096 | .708913 | 1.4106098 | 1.22579 | .815801 | 40 |
| 30 | .580703 | 1.7220508 | .713293 | 1.4019483 | 1.22833 | .814116 | 30 |
| 40 | .583069 | 1.7150639 | .717691 | 1.3933571 | 1.23089 | .812423 | 20 |
| 50 | .585429 | 1.7081478 | .722108 | 1.3848355 | 1.23347 | .810723 | 10 |
| 36° 0′ | .587785 | 1.7013016 | .726543 | 1.3763810 | 1.23607 | .809017 | 54° 0′ |
| 10 | .590136 | 1.6945244 | .730996 | 1.3679959 | 1.23869 | .807304 | 50 |
| 20 | .592482 | 1.6878151 | .735469 | 1.3596764 | 1.24134 | .805584 | 40 |
| 30 | .594823 | 1.6811730 | .739961 | 1.3514224 | 1.24400 | .803857 | 30 |
| 40 | .597159 | 1.6745970 | .744472 | 1.3432331 | 1.24669 | .802123 | 20 |
| 50 | .599489 | 1.6680864 | .749003 | 1.3351075 | 1.24940 | .800383 | 10 |
| 37° 0′ | .601815 | 1.6616401 | .753554 | 1.3270448 | 1.25214 | .798636 | 53° 0′ |
| 10 | .604136 | 1.6552575 | .758125 | 1.3190441 | 1.25489 | .796882 | 50 |
| 20 | .606451 | 1.6489376 | .762716 | 1.3111046 | 1.25767 | .795121 | 40 |
| 30 | .608761 | 1.6426796 | .767627 | 1.3032254 | 1.26047 | .793353 | 30 |
| 40 | .611067 | 1.6364828 | .771959 | 1.2954057 | 1.26330 | .791579 | 20 |
| 50 | .613367 | 1.6303462 | .776612 | 1.2876447 | 1.26615 | .789798 | 10 |
| 38° 0′ | .615661 | 1.6242692 | .781286 | 1.2799416 | 1.26902 | .788011 | 52° 0′ |
| 10 | .617951 | 1.6182510 | .785981 | 1.2722957 | 1.27191 | .786217 | 50 |
| 20 | .620235 | 1.6122908 | .790698 | 1.2647062 | 1.27483 | .784416 | 40 |
| 30 | .622515 | 1.6063879 | .795436 | 1.2571723 | 1.27778 | .782608 | 30 |
| 40 | .624789 | 1.6005416 | .800196 | 1.2496933 | 1.28075 | .780794 | 20 |
| 50 | .627057 | 1.5947511 | .804080 | 1.2422685 | 1.28374 | .778973 | 10 |
| | Cosine | Secant | Cotangent | Tangent | Cosecant | Sine | Angle |

SINES, COSINES, TANGENTS, ETC.—(*Cont.*)

| Angle | Sine | Cosecant | Tangent | Cotangent | Secant | Cosine | |
|---|---|---|---|---|---|---|---|
| 39° 0′ | .629320 | 1.5890157 | .809784 | 1.2348972 | 1.28676 | .777146 | 51° 0′ |
| 10 | .631578 | 1.5833318 | .814612 | 1.2275786 | 1.28980 | .775312 | 50 |
| 20 | .633831 | 1.5777077 | .819463 | 1.2203121 | 1.29287 | .773472 | 40 |
| 30 | .636078 | 1.5721337 | .824336 | 1.2130970 | 1.29597 | .771625 | 30 |
| 40 | .638320 | 1.5666121 | .829234 | 1.2059327 | 1.29909 | .769771 | 20 |
| 50 | .640557 | 1.5611424 | .834155 | 1.1988184 | 1.30223 | .767911 | 10 |
| 40° 0′ | .642788 | 1.5557238 | .839100 | 1.1917536 | 1.30541 | .766044 | 50° 0′ |
| 10 | .645013 | 1.5503558 | .844069 | 1.1847376 | 1.30861 | .764171 | 50 |
| 20 | .647233 | 1.5450378 | .849062 | 1.1777698 | 1.31183 | .762292 | 40 |
| 30 | .649448 | 1.5397690 | .854081 | 1.1708496 | 1.31509 | .760406 | 30 |
| 40 | .651657 | 1.5345491 | .859124 | 1.1639763 | 1.31837 | .758514 | 20 |
| 50 | .653861 | 1.5293773 | .864193 | 1.1571495 | 1.32168 | .756615 | 10 |
| 41° 0′ | .656059 | 1.5242531 | .869287 | 1.1503684 | 1.32501 | .754710 | 49° 0′ |
| 10 | .658252 | 1.5191759 | .874407 | 1.1436326 | 1.32838 | .752798 | 50 |
| 20 | .660439 | 1.5141452 | .879553 | 1.1369414 | 1.33177 | .750880 | 40 |
| 30 | .662620 | 1.5091605 | .884725 | 1.1302944 | 1.33519 | .748956 | 30 |
| 40 | .664796 | 1.5042211 | .889924 | 1.1236909 | 1.33864 | .747025 | 20 |
| 50 | .666966 | 1.4993267 | .895151 | 1.1171305 | 1.34212 | .745088 | 10 |
| 42° 0′ | .669131 | 1.4944765 | .900404 | 1.1106125 | 1.34563 | .743145 | 48° 0′ |
| 10 | .671289 | 1.4896703 | .905685 | 1.1041365 | 1.34917 | .741195 | 50 |
| 20 | .673443 | 1.4849073 | .910994 | 1.0977020 | 1.35274 | .739239 | 40 |
| 30 | .675590 | 1.4801872 | .916331 | 1.0913085 | 1.35634 | .737277 | 30 |
| 40 | .677732 | 1.4755095 | .921697 | 1.0849554 | 1.35997 | .735309 | 20 |
| 50 | .679868 | 1.4708736 | .927091 | 1.0786423 | 1.36363 | .733335 | 10 |
| 43° 0′ | .681998 | 1.4662792 | .932515 | 1.0723687 | 1.36733 | .731354 | 47° 0′ |
| 10 | .684123 | 1.4617257 | .937968 | 1.0661341 | 1.37105 | .729367 | 50 |
| 20 | .686242 | 1.4572127 | .943451 | 1.0599381 | 1.37481 | .727374 | 40 |
| 30 | .688355 | 1.4527397 | .948965 | 1.0537801 | 1.37860 | .725374 | 30 |
| 40 | .690462 | 1.4483063 | .954508 | 1.0476598 | 1.38242 | .723369 | 20 |
| 50 | .692563 | 1.4439120 | .960083 | 1.0415767 | 1.38628 | .721357 | 10 |
| 44° 0′ | .694658 | 1.4395565 | .965689 | 1.0355303 | 1.39016 | .719340 | 46° 0′ |
| 10 | .696748 | 1.4352393 | .971326 | 1.0295203 | 1.39409 | .717316 | 50 |
| 20 | .698832 | 1.4309602 | .976996 | 1.0235461 | 1.39804 | .715286 | 40 |
| 30 | .700909 | 1.4267182 | .982697 | 1.0176074 | 1.40203 | .713251 | 30 |
| 40 | .702981 | 1.4225134 | .988432 | 1.0117088 | 1.40606 | .711209 | 20 |
| 50 | .705047 | 1.4183454 | .994199 | 1.0058348 | 1.41012 | .709161 | 10 |
| 45° 0′ | .707107 | 1.4142136 | 1.000000 | 1.0000000 | 1.41421 | .707107 | 45° 0′ |
| | Cosine | Secant | Cotangent | Tangent | Cosecant | Sine | Angle |

## LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS OF ANGLES FROM 0° TO 90°

This table is constructed similarly to the table of natural sines, etc., preceding. To avoid the use of logarithms with negative indices, the radius is assumed, instead of being equal to 1, to be equal to $10^{1°}$, or 10,000,000,000; consequently, the logarithm of the radius = 10 log 10 = 10. Whence, if to log sine of any angle, when calculated for a radius = 1, there be added 10, the sum will be the log sine of that angle for a radius = $10^{1°}$.

For example, to find the logarithmic sine of the angle 15° 50′:

$$\begin{aligned} \text{Nat. sine } 15°\,50' = .272840;\ \text{its log} &= \bar{1}.435908 \\ \text{add} &= 10 \\ \hline \text{Logarithmic sine of } 15°\,50' &= 9.435908 \end{aligned}$$

When the logarithmic sines and cosines have been found in this manner, the logarithmic tangents, cotangents, secants, and cosecants are found from those by addition or subtraction, according to the correlations of the trigonometrical elements already given, and here repeated in logarithmic form:

log tan........................ = 10 + log sin − log cosin
log cotan...................... = 20 − log tan
log sec........................ = 20 − log cosin
log cosec...................... = 20 − log sin

**To Find the Logarithmic Sine, Tangent, etc., of Any Angle.**—When the number of degrees is less than 45°, find the degrees and minutes in the left-hand column headed *angle*, and under the heading *sine* or *tangent*, etc., as required, the logarithm is found in a line with the angle.

When the number of degrees is above 45°, and less than 90°, find the degrees and minutes in the right-hand column headed *angle*, and in the same line, above the title at the foot of the page, *sine* or *tangent*, etc., find the logarithm in a line with the angle.

When the number of degrees is between 90° and 180°, take their supplement to 180°; when between 180° and 270°, diminish them by 180°; and when between 270° and 360°, take their complement to 360°, and find the logarithm of the remainder as before.

If the exact number of minutes is not found in the table, the logarithm of the nearest tabular angle is to be taken and increased or diminished, as the case may be, by the due proportion of the difference of the logarithms of the angles greater and less than the given angle.

LOGARITHMIC SINES, COSINES, TANGENTS, AND COTANGENTS OF ANGLES FROM 0° TO 90°

Advancing by 10′, or one-sixth of a Degree

| Angle | Sine | Tangent | Cotangent | Cosine | |
|---|---|---|---|---|---|
| 0° | 0.000000 | 0.000000 | Infinite | 10.000000 | 90° |
| 10′ | 7.463726 | 7.463727 | 12.536273 | 9.999998 | 50′ |
| 20 | 7.764754 | 7.764761 | 12.235239 | 9.999993 | 40 |
| 30 | 7.940842 | 7.940858 | 12.059142 | 9.999983 | 30 |
| 40 | 8.065776 | 8.065806 | 11.934194 | 9.999971 | 20 |
| 50 | 8.162681 | 8.162727 | 11.837273 | 9.999954 | 10 |
| 1° | 8.241855 | 8.241921 | 11.758079 | 9.999934 | 89° |
| 10′ | 8.308794 | 8.308884 | 11.691116 | 9.999910 | 50′ |
| 20 | 8.366777 | 8.366895 | 11.633105 | 9.999882 | 40 |
| 30 | 8.417919 | 8.418068 | 11.581932 | 9.999851 | 30 |
| 40 | 8.463665 | 8.463849 | 11.536151 | 9.999816 | 20 |
| 50 | 8.505045 | 8.505267 | 11.494733 | 9.999778 | 10 |
| 2° | 8.542819 | 8.543084 | 11.456916 | 9.999735 | 88° |
| 10′ | 8.577566 | 8.577877 | 11.422123 | 9.999689 | 50′ |
| 20 | 8.609734 | 8.610094 | 11.389906 | 9.999640 | 40 |
| 30 | 8.639680 | 8.640093 | 11.359907 | 9.999586 | 30 |
| 40 | 8.667689 | 8.668160 | 11.331840 | 9.999529 | 20 |
| 50 | 8.693998 | 8.694529 | 11.305471 | 9.999469 | 10 |
| 3° | 8.718800 | 8.719396 | 11.280604 | 9.999404 | 87° |
| 10′ | 8.742259 | 8.742922 | 11.257078 | 9.999336 | 50′ |
| 20 | 8.764511 | 8.765246 | 11.234754 | 9.999265 | 40 |
| 30 | 8.785675 | 8.786486 | 11.213514 | 9.999189 | 30 |
| 40 | 8.805852 | 8.806742 | 11.193258 | 9.999110 | 20 |
| 50 | 8.825130 | 8.826103 | 11.173897 | 9.999027 | 10 |
| 4° | 8.843585 | 8.844644 | 11.155356 | 9.998941 | 86° |
| 10′ | 8.861283 | 8.862433 | 11.137567 | 9.998851 | 50′ |
| 20 | 8.878285 | 8.879529 | 11.120471 | 9.998757 | 40 |
| 30 | 8.894643 | 8.895984 | 11.104016 | 9.998659 | 30 |
| 40 | 8.910404 | 8.911846 | 11.088154 | 9.998558 | 20 |
| 50 | 8.925609 | 8.927156 | 11.072844 | 9.998453 | 10 |
| 5° | 8.940296 | 8.941952 | 11.058048 | 9.998344 | 85° |
| 10′ | 8.954499 | 8.956267 | 11.043733 | 9.998232 | 50′ |
| 20 | 8.968249 | 8.970133 | 11.029867 | 9.998116 | 40 |
| 30 | 8.981573 | 8.983577 | 11.016423 | 9.997996 | 30 |
| 40 | 8.994497 | 8.996624 | 11.003376 | 9.997872 | 20 |
| 50 | 9.007044 | 9.009298 | 10.990702 | 9.997745 | 10 |
| 6° | 9.019235 | 9.021620 | 10.978380 | 9.997614 | 84° |
| 10′ | 9.031089 | 9.033609 | 10.966391 | 9.997480 | 50′ |
| 20 | 9.042625 | 9.045284 | 10.954716 | 9.997341 | 40 |
| 30 | 9.053859 | 9.056659 | 10.943341 | 9.997199 | 30 |
| 40 | 9.064806 | 9.067752 | 10.932248 | 9.997053 | 20 |
| 50 | 9.075480 | 9.078576 | 10.921424 | 9.996904 | 10 |
| | Cosine | Cotangent | Tangent | Sine | Angle |

LOGARITHMIC SINES, COSINES, TANGENTS, ETC.—(*Cont.*)

| Angle | Sine | Tangent | Cotangent | Cosine | |
|---|---|---|---|---|---|
| 7° | 9.085894 | 9.089144 | 10.910856 | 9.996751 | 83° |
| 10′ | 9.096062 | 9.099468 | 10.900532 | 9.996594 | 50′ |
| 20 | 9.105992 | 9.109559 | 10.890441 | 9.996433 | 40 |
| 30 | 9.115698 | 9.119429 | 10.880571 | 9.996269 | 30 |
| 40 | 9.125187 | 9.129087 | 10.870913 | 9.996100 | 20 |
| 50 | 9.134470 | 9.138542 | 10.861458 | 9.995928 | 10 |
| 8° | 9.143555 | 9.147803 | 10.852197 | 9.995753 | 82° |
| 10′ | 9.152451 | 9.156877 | 10.843123 | 9.995573 | 50′ |
| 20 | 9.161164 | 9.165774 | 10.834226 | 9.995390 | 40 |
| 30 | 9.169702 | 9.174499 | 10.825501 | 9.995203 | 30 |
| 40 | 9.178072 | 9.183059 | 10.816941 | 9.995013 | 20 |
| 50 | 9.186280 | 9.191462 | 10.808538 | 9.994818 | 10 |
| 9° | 9.194332 | 9.199713 | 10.800287 | 9.994620 | 81° |
| 10′ | 9.202234 | 9.207817 | 10.792183 | 9.994418 | 50′ |
| 20 | 9.209992 | 9.215780 | 10.784220 | 9.994212 | 40 |
| 30 | 9.217609 | 9.223607 | 10.776393 | 9.994003 | 30 |
| 40 | 9.225092 | 9.231302 | 10.768698 | 9.993789 | 20 |
| 50 | 9.232444 | 9.238872 | 10.761128 | 9.993572 | 10 |
| 10° | 9.239670 | 9.246319 | 10.753681 | 9.993351 | 80° |
| 10′ | 9.246775 | 9.253648 | 10.746352 | 9.993127 | 50′ |
| 20 | 9.253761 | 9.260863 | 10.739137 | 9.992898 | 40 |
| 30 | 9.260633 | 9.267967 | 10.732033 | 9.992666 | 30 |
| 40 | 9.267395 | 9.274964 | 10.725036 | 9.992430 | 20 |
| 50 | 9.274049 | 9.281858 | 10.718142 | 9.992190 | 10 |
| 11° | 9.280599 | 9.288652 | 10.711348 | 9.991947 | 79° |
| 10′ | 9.287048 | 9.295349 | 10.704651 | 9.991699 | 50′ |
| 20 | 9.293399 | 9.301951 | 10.698049 | 9.991448 | 40 |
| 30 | 9.299655 | 9.308463 | 10.691537 | 9.991193 | 30 |
| 40 | 9.305819 | 9.314885 | 10.685115 | 9.990934 | 20 |
| 50 | 9.311893 | 9.321222 | 10.678778 | 9.990671 | 10 |
| 12° | 9.317879 | 9.327475 | 10.672525 | 9.990404 | 78° |
| 10′ | 9.323780 | 9.333646 | 10.666354 | 9.990134 | 50′ |
| 20 | 9.329599 | 9.339739 | 10.660261 | 9.989860 | 40 |
| 30 | 9.335337 | 9.345755 | 10.654245 | 9.989582 | 30 |
| 40 | 9.340996 | 9.351697 | 10.648303 | 9.989300 | 20 |
| 50 | 9.346779 | 9.357566 | 10.642434 | 9.989014 | 10 |
| 13° | 9.352088 | 9.363364 | 10.636636 | 9.988724 | 77° |
| 10′ | 9.357524 | 9.369094 | 10.630906 | 9.988430 | 50′ |
| 20 | 9.362889 | 9.374756 | 10.625244 | 9.988133 | 40 |
| 30 | 9.368185 | 9.380354 | 10.619646 | 9.987832 | 30 |
| 40 | 9.373414 | 9.385888 | 10.614112 | 9.987526 | 20 |
| 50 | 9.378577 | 9.391360 | 10.608640 | 9.987217 | 10 |
| | Cosine | Cotangent | Tangent | Sine | Angle |

LOGARITHMIC SINES, COSINES, TANGENTS, ETC.—(*Cont.*)

| Angle | Sine | Tangent | Cotangent | Cosine | |
|---|---|---|---|---|---|
| 14° | 9.383675 | 9.396771 | 10.603229 | 9.986904 | 76° |
| 10′ | 9.388711 | 9.402124 | 10.597876 | 9.986587 | 50′ |
| 20 | 9.393685 | 9.407419 | 10.592581 | 9.986266 | 40 |
| 30 | 9.398600 | 9.412658 | 10.587342 | 9.985942 | 30 |
| 40 | 9.403455 | 9.417842 | 10.582158 | 9.985613 | 20 |
| 50 | 9.408254 | 9.422974 | 10.577026 | 9.985280 | 10 |
| 15° | 9.412996 | 9.428052 | 10.571948 | 9.984944 | 75° |
| 10′ | 9.417684 | 9.433080 | 10.566920 | 9.984603 | 50′ |
| 20 | 9.422318 | 9.438059 | 10.561941 | 9.984259 | 40 |
| 30 | 9.426899 | 9.442988 | 10.557012 | 9.983911 | 30 |
| 40 | 9.431429 | 9.447870 | 10.552130 | 9.983558 | 20 |
| 50 | 9.435908 | 9.452706 | 10.547294 | 9.983202 | 10 |
| 16° | 9.440338 | 9.457496 | 10.542504 | 9.982842 | 74° |
| 10′ | 9.444720 | 9.462242 | 10.537758 | 9.982477 | 50′ |
| 20 | 9.449054 | 9.466945 | 10.533055 | 9.982109 | 40 |
| 30 | 9.453342 | 9.471605 | 10.528395 | 9.981737 | 30 |
| 40 | 9.457584 | 9.476223 | 10.523777 | 9.981361 | 20 |
| 50 | 9.461782 | 9.480801 | 10.519199 | 9.980981 | 10 |
| 17° | 9.465935 | 9.485339 | 10.514661 | 9.980596 | 73° |
| 10′ | 9.470046 | 9.489838 | 10.510162 | 9.980208 | 50′ |
| 20 | 9.474115 | 9.494299 | 10.505701 | 9.979816 | 40 |
| 30 | 9.478142 | 9.498722 | 10.501278 | 9.979420 | 30 |
| 40 | 9.482128 | 9.503109 | 10.496891 | 9.979019 | 20 |
| 50 | 9.486075 | 9.507460 | 10.492540 | 9.978615 | 10 |
| 18° | 9.489982 | 9.511776 | 10.488224 | 9.978206 | 72° |
| 10′ | 9.493851 | 9.516057 | 10.483943 | 9.977794 | 50′ |
| 20 | 9.497682 | 9.520305 | 10.479695 | 9.977377 | 40 |
| 30 | 9.501476 | 9.524520 | 10.475480 | 9.976957 | 30 |
| 40 | 9.505234 | 9.528702 | 10.471298 | 9.976532 | 20 |
| 50 | 9.508956 | 9.532853 | 10.467147 | 9.976103 | 10 |
| 19° | 9.512642 | 9.536972 | 10.463028 | 9.975670 | 71° |
| 10′ | 9.516294 | 9.541061 | 10.458939 | 9.975233 | 50′ |
| 20 | 9.519911 | 9.545119 | 10.454881 | 9.974792 | 40 |
| 30 | 9.523495 | 9.549149 | 10.450851 | 9.974347 | 30 |
| 40 | 9.527046 | 9.553149 | 10.446851 | 9.973897 | 20 |
| 50 | 9.530565 | 9.557121 | 10.442879 | 9.973444 | 10 |
| 20° | 9.534052 | 9.561066 | 10.438934 | 9.972986 | 70° |
| 10′ | 9.537507 | 9.564983 | 10.435017 | 9.972524 | 50′ |
| 20 | 9.540931 | 9.568873 | 10.431127 | 9.972058 | 40 |
| 30 | 9.544325 | 9.572738 | 10.427262 | 9.971588 | 30 |
| 40 | 9.547689 | 9.576576 | 10.423424 | 9.971113 | 20 |
| 50 | 9.551024 | 9.580389 | 10.419611 | 9.970635 | 10 |
| | Cosine | Cotangent | Tangent | Sine | Angle |

LOGARITHMIC SINES, COSINES, TANGENTS, ETC.—(*Cont.*)

| Angle | Sine | Tangent | Cotangent | Cosine | |
|---|---|---|---|---|---|
| 21° | 9.554329 | 9.584177 | 10.415823 | 9.970152 | 69° |
| 10′ | 9.557606 | 9.587941 | 10.412059 | 9.969665 | 50′ |
| 20 | 9.560855 | 9.591681 | 10.408319 | 9.969173 | 40 |
| 30 | 9.564075 | 9.595398 | 10.404602 | 9.968678 | 30 |
| 40 | 9.567269 | 9.599091 | 10.400909 | 9.968178 | 20 |
| 50 | 9.570435 | 9.602761 | 10.397239 | 9.967674 | 10 |
| 22° | 9.573575 | 9.606410 | 10.393590 | 9.967166 | 68° |
| 10′ | 9.576689 | 9.610036 | 10.389964 | 9.966653 | 50 |
| 20 | 9.579777 | 9.613641 | 10.386359 | 9.966136 | 40 |
| 30 | 9.582840 | 9.617224 | 10.382776 | 9.965615 | 30 |
| 40 | 9.585877 | 9.620787 | 10.379213 | 9.965090 | 20 |
| 50 | 9.588890 | 9.624330 | 10.375670 | 9.964560 | 10 |
| 23° | 9.591878 | 9.627852 | 10.372148 | 9.964026 | 67° |
| 10′ | 9.594842 | 9.631355 | 10.368645 | 9.963488 | 50′ |
| 20 | 9.597783 | 9.634838 | 10.365162 | 9.962945 | 40 |
| 30 | 9.600700 | 9.638302 | 10.361698 | 9.962398 | 30 |
| 40 | 9.603594 | 9.641747 | 10.358253 | 9.961846 | 20 |
| 50 | 9.606465 | 9.645174 | 10.354826 | 9.961290 | 10 |
| 24° | 9.609313 | 9.648583 | 10.351417 | 9.960730 | 66° |
| 10′ | 9.612140 | 9.651974 | 10.348026 | 9.960165 | 50′ |
| 20 | 9.614944 | 9.655348 | 10.344652 | 9.959596 | 40 |
| 30 | 9.617727 | 9.658704 | 10.341296 | 9.959023 | 30 |
| 40 | 9.620488 | 9.662043 | 10.337957 | 9.958445 | 20 |
| 50 | 9.623229 | 9.665366 | 10.334634 | 9.957863 | 10 |
| 25° | 9.625948 | 9.668673 | 10.331328 | 9.957276 | 65° |
| 10′ | 9.628647 | 9.671963 | 10.328037 | 9.956684 | 50′ |
| 20 | 9.631326 | 9.675237 | 10.324763 | 9.956089 | 40 |
| 30 | 9.633984 | 9.678496 | 10.321504 | 9.955488 | 30 |
| 40 | 9.636623 | 9.681740 | 10.318260 | 9.954883 | 20 |
| 50 | 9.639242 | 9.684968 | 10.315032 | 9.954274 | 10 |
| 26° | 9.641842 | 9.688182 | 10.311818 | 9.953660 | 64° |
| 10′ | 9.644423 | 9.691381 | 10.308619 | 9.953042 | 50′ |
| 20 | 9.646984 | 9.694566 | 10.305434 | 9.952419 | 40 |
| 30 | 9.649527 | 9.697736 | 10.302264 | 9.951791 | 30 |
| 40 | 9.652052 | 9.700893 | 10.299107 | 9.951159 | 20 |
| 50 | 9.654558 | 9.704036 | 10.295964 | 9.950522 | 10 |
| 27° | 9.657047 | 9.707166 | 10.292834 | 9.949881 | 63° |
| 10′ | 9.659517 | 9.710282 | 10.289718 | 9.949235 | 50′ |
| 20 | 9.661970 | 9.713386 | 10.286614 | 9.948584 | 40 |
| 30 | 9.664406 | 9.716477 | 10.283523 | 9.947929 | 30 |
| 40 | 9.666824 | 9.719555 | 10.280445 | 9.947269 | 20 |
| 50 | 9.669225 | 9.722621 | 10.277379 | 9.946604 | 10 |
| | Cosine | Cotangent | Tangent | Sine | Angle |

LOGARITHMIC SINES, COSINES, TANGENTS, ETC.—(*Cont.*)

| Angle | Sine | Tangent | Cotangent | Cosine | |
|---|---|---|---|---|---|
| 28° | 9.671609 | 9.725674 | 10.274326 | 9.945935 | 62° |
| 10′ | 9.673977 | 9.728716 | 10.271284 | 9.945261 | 50′ |
| 20 | 9.676328 | 9.731746 | 10.268254 | 9.944582 | 40 |
| 30 | 9.678663 | 9.734764 | 10.265236 | 9.943899 | 30 |
| 40 | 9.680982 | 9.737771 | 10.262229 | 9.943210 | 20 |
| 50 | 9.683284 | 9.740767 | 10.259233 | 9.942517 | 10 |
| 29° | 9.685571 | 9.743752 | 10.256248 | 9.941819 | 61° |
| 10′ | 9.687843 | 9.746726 | 10.253274 | 9.941117 | 50′ |
| 20 | 9.690098 | 9.749689 | 10.250311 | 9.940409 | 40 |
| 30 | 9.692339 | 9.752642 | 10.247358 | 9.939697 | 30 |
| 40 | 9.694564 | 9.755585 | 10.244415 | 9.938980 | 20 |
| 50 | 9.696775 | 9.758517 | 10.241483 | 9.938258 | 10 |
| 30° | 9.698970 | 9.761439 | 10.238561 | 9.937531 | 60° |
| 10′ | 9.701151 | 9.764352 | 10.235648 | 9.936799 | 50′ |
| 20 | 9.703317 | 9.767255 | 10.232745 | 9.936062 | 40 |
| 30 | 9.705469 | 9.770148 | 10.229852 | 9.935320 | 30 |
| 40 | 9.707606 | 9.773033 | 10.226967 | 9.934574 | 20 |
| 50 | 9.709730 | 9.775908 | 10.224092 | 9.933822 | 10 |
| 31° | 9.711839 | 9.778774 | 10.221226 | 9.933066 | 59° |
| 10′ | 9.713935 | 9.781631 | 10.218369 | 9.932304 | 50′ |
| 20 | 9.716017 | 9.784479 | 10.215521 | 9.931537 | 40 |
| 30 | 9.718085 | 9.787319 | 10.212681 | 9.930766 | 30 |
| 40 | 9.720140 | 9.790151 | 10.209849 | 9.929989 | 20 |
| 50 | 9.722181 | 9.792974 | 10.207026 | 9.929207 | 10 |
| 32° | 9.724210 | 9.795789 | 10.204211 | 9.928420 | 58° |
| 10′ | 9.726225 | 9.798596 | 10.201404 | 9.927629 | 50′ |
| 20 | 9.728227 | 9.801396 | 10.198604 | 9.926831 | 40 |
| 30 | 9.730217 | 9.804187 | 10.195813 | 9.926029 | 30 |
| 40 | 9.732193 | 9.806971 | 10.193029 | 9.925222 | 20 |
| 50 | 9.734147 | 9.809748 | 10.190252 | 9.924409 | 10 |
| 33° | 9.736109 | 9.812517 | 10.187483 | 9.923591 | 57° |
| 10′ | 9.738048 | 9.815280 | 10.184720 | 9.922768 | 50′ |
| 20 | 9.739975 | 9.818035 | 10.181965 | 9.921940 | 40 |
| 30 | 9.741889 | 9.820783 | 10.179217 | 9.921107 | 30 |
| 40 | 9.743792 | 9.823524 | 10.176476 | 9.920268 | 20 |
| 50 | 9.745683 | 9.826259 | 10.173741 | 9.919424 | 10 |
| 34° | 9.747562 | 9.828987 | 10.171013 | 9.918574 | 56° |
| 10′ | 9.749429 | 9.831709 | 10.168291 | 9.917719 | 50′ |
| 20 | 9.751284 | 9.834425 | 10.165575 | 9.916859 | 40 |
| 30 | 9.753128 | 9.837134 | 10.162866 | 9.915994 | 30 |
| 40 | 9.754960 | 9.839838 | 10.160162 | 9.915123 | 20 |
| 50 | 9.756782 | 9.842535 | 10.157465 | 9.914246 | 10 |
| | Cosine | Cotangent | Tangent | Sine | Angle |

LOGARITHMIC SINES, COSINES, TANGENTS, ETC.—(*Cont.*)

| Angle | Sine | Tangent | Cotangent | Cosine | |
|---|---|---|---|---|---|
| 35° | 9.758591 | 9.845227 | 10.154773 | 9.913365 | 55° |
| 10′ | 9.760390 | 9.847913 | 10.152087 | 9.912477 | 50′ |
| 20 | 9.762177 | 9.850593 | 10.149407 | 9.911584 | 40 |
| 30 | 9.763954 | 9.853268 | 10.146732 | 9.910686 | 30 |
| 40 | 9.765720 | 9.855938 | 10.144062 | 9.909782 | 20 |
| 50 | 9.767475 | 9.858602 | 10.141398 | 9.908873 | 10 |
| 36° | 9.769219 | 9.861261 | 10.138739 | 9.907958 | 54° |
| 10′ | 9.770952 | 9.863915 | 10.136085 | 9.907037 | 50′ |
| 20 | 9.772675 | 9.866564 | 10.133436 | 9.906111 | 40 |
| 30 | 9.774388 | 9.869209 | 10.130791 | 9.905179 | 30 |
| 40 | 9.776090 | 9.871849 | 10.128151 | 9.904241 | 20 |
| 50 | 9.777781 | 9.874474 | 10.125516 | 9.903298 | 10 |
| 37° | 9.779463 | 9.877114 | 10.122886 | 9.902349 | 53° |
| 10′ | 9.781134 | 9.879741 | 10.120259 | 9.901394 | 50′ |
| 20 | 9.782796 | 9.882363 | 10.117637 | 9.900433 | 40 |
| 30 | 9.784447 | 9.884980 | 10.115020 | 9.899467 | 30 |
| 40 | 9.786089 | 9.887594 | 10.112406 | 9.898494 | 20 |
| 50 | 9.787720 | 9.890204 | 10.109796 | 9.897516 | 10 |
| 38° | 9.789342 | 9.892810 | 10.107190 | 9.896532 | 52° |
| 10′ | 9.790854 | 9.895412 | 10.104588 | 9.895542 | 50′ |
| 20 | 9.792557 | 9.898010 | 10.101990 | 9.894546 | 40 |
| 30 | 9.794150 | 9.900605 | 10.099395 | 9.893344 | 30 |
| 40 | 9.795733 | 9.903197 | 10.096803 | 9.892536 | 20 |
| 50 | 9.797307 | 9.905785 | 10.094215 | 9.891523 | 10 |
| 39° | 9.798872 | 9.908369 | 10.091631 | 9.890503 | 51° |
| 10′ | 9.800427 | 9.910951 | 10.089049 | 9.889477 | 50′ |
| 20 | 9.801973 | 9.913529 | 10.086471 | 9.888444 | 40 |
| 30 | 9.803511 | 9.916104 | 10.083896 | 9.887406 | 30 |
| 40 | 9.805039 | 9.918677 | 10.081323 | 9.886362 | 20 |
| 50 | 9.806557 | 9.921247 | 10.078753 | 9.885311 | 10 |
| 40° | 9.808067 | 9.923814 | 10.076186 | 9.884254 | 50° |
| 10′ | 9.809569 | 9.926378 | 10.073622 | 9.883191 | 50′ |
| 20 | 9.811061 | 9.928940 | 10.071060 | 9.882121 | 40 |
| 30 | 9.812544 | 9.931499 | 10.068501 | 9.881046 | 30 |
| 40 | 9.814019 | 9.934056 | 10.065944 | 9.879963 | 20 |
| 50 | 9.815485 | 9.936611 | 10.063389 | 9.878875 | 10 |
| 41° | 9.816943 | 9.939163 | 10.060837 | 9.877780 | 49° |
| 10′ | 9.818392 | 9.941713 | 10.058287 | 9.876678 | 50′ |
| 20 | 9.819832 | 9.944262 | 10.055738 | 9.875571 | 40 |
| 30 | 9.821265 | 9.946808 | 10.053192 | 9.874456 | 30 |
| 40 | 9.822688 | 9.949353 | 10.050647 | 9.873335 | 20 |
| 50 | 9.824104 | 9.951896 | 10.048104 | 9.872208 | 10 |
| | Cosine | Cotangent | Tangent | Sine | Angle |

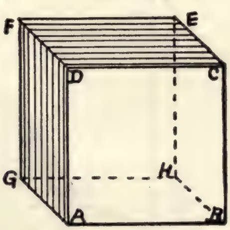
LOGARITHMIC SINES, COSINES, TANGENTS, ETC.—(*Cont.*)

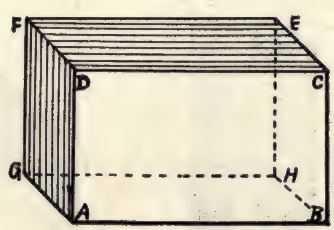
| Angle | Sine | Tangent | Cotangent | Cosine | |
|---|---|---|---|---|---|
| 42° | 9.825511 | 9.954437 | 10.045563 | 9.871073 | 48° |
| 10′ | 9.826910 | 9.956977 | 10.043023 | 9.869933 | 50′ |
| 20 | 9.828301 | 9.959516 | 10.040484 | 9.868785 | 40 |
| 30 | 9.829683 | 9.962052 | 10.037948 | 9.867631 | 30 |
| 40 | 9.831058 | 9.964588 | 10.035412 | 9.866470 | 20 |
| 50 | 9.832425 | 9.967123 | 10.032877 | 9.865302 | 10 |
| 43° | 9.833783 | 9.969656 | 10.030344 | 9.864127 | 47° |
| 10′ | 9.835134 | 9.972188 | 10.027812 | 9.862946 | 50′ |
| 20 | 9.836477 | 9.974720 | 10.025280 | 9.861758 | 40 |
| 30 | 9.837812 | 9.977250 | 10.022750 | 9.860562 | 30 |
| 40 | 9.839140 | 9.979780 | 10.020220 | 9.859360 | 20 |
| 50 | 9.840459 | 9.982309 | 10.017691 | 9.858151 | 10 |
| 44° | 9.841771 | 9.984837 | 10.015163 | 9.856934 | 46° |
| 10′ | 9.843076 | 9.987365 | 10.012635 | 9.855711 | 50′ |
| 20 | 9.844372 | 9.989893 | 10.010107 | 9.854480 | 40 |
| 30 | 9.845662 | 9.992420 | 10.007580 | 9.853242 | 30 |
| 40 | 9.846944 | 9.994947 | 10.005053 | 9.851997 | 20 |
| 50 | 9.848218 | 9.997473 | 10.002527 | 9.850745 | 10 |
| 45° | 9.849485 | 10.000000 | 10.000000 | 9.849485 | 45° |
| | Cosine | Cotangent | Tangent | Sine | Angle |

## MENSURATION OF SOLIDS

**To Find the Solidity of a Cube.**—Rule: Multiply the side of the cube by itself and that product again by the side.

NOTE.—The surface of the cube is equal to six times the square of its side.




**To Find the Solidity of a Parallelepipedon.**—Rule: Multiply the length by the breadth and that product by the depth or altitude.

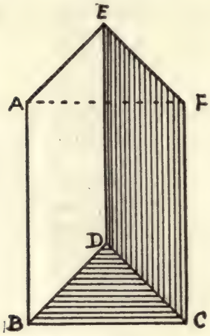
NOTE.—The surface of the parallelepipedon is equal to the sum of the areas of each of its sides or ends.

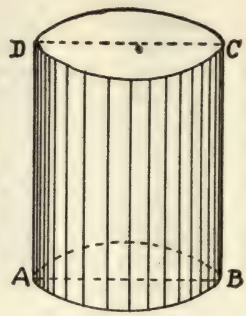
**To Find the Solidity of a Prism.**—Rule: Multiply the area of the base into the perpendicular height of the prism.

NOTE.—The surface of a prism is equal to the sum of the areas of the two ends and each of its sides.

**To Find the Convex Surface of a Cylinder.**—Rule: Multiply the circumference of the base by the height of the cylinder.

NOTE.—If twice the area of either of the ends be added to the convex surface, it will give the whole surface of the cylinder.




**To Find the Solidity of a Cylinder.**—Rule: Multiply the area of the base by the perpendicular height.

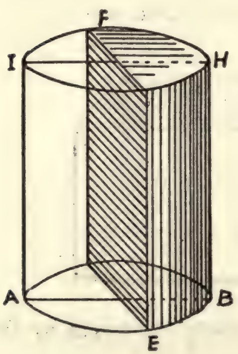
NOTE.—The four following cases contain all the rules for finding the superfices and solidities of *cylindric ungulas.*

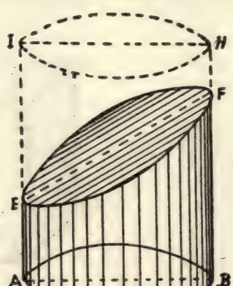
**Case 1. When the Section is Parallel to the Axis of the Cylinder.**—Rule 1. Multiply the length of the arc line of the base by the height of the cylinder, the product will be the curve surface.

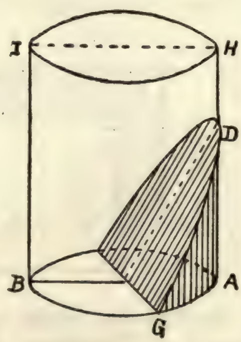
Rule 2. Multiply the area of the base by the height of the cylinder, the product will be the solidity.

**Case 2. When the Section Passes Obliquely Through the Opposite Sides of the Cylinder.**—Rule 1. Multiply the circumference of the base of the cylinder by half the sum of the greatest and least lengths of the ungula, the product will be the curve surface.

Rule 2. Multiply the area of the base of the cylinder by half the sum of the greatest and least lengths of the ungula, the product will be the solidity.




**Case 3. When the Section Passes Through the Base of the Cylinder, and One of its Sides.**—Rule 1. Multiply the sine of half the arc of the base by the diameter of the cylinder, and from this product subtract the product of the arc and cosine.

Rule 2. Multiply the difference thus found, by the quotient of the height divided by the versed sine, the product will be the curve surface.

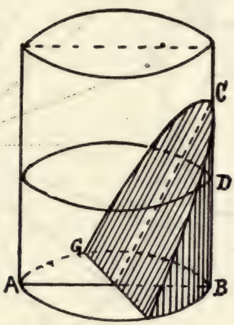
Rule 3. From two-thirds of the cube of the right sine of half the arc of the base, subtract the product of the area of the base and the cosine of the said half arc.

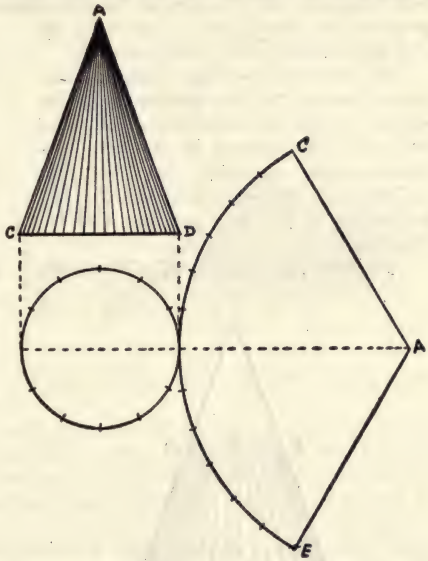
Multiply the difference thus found by the quotient arising from the height divided by the versed sine, the product will be the solidity.

**Case 4. When the Section Passes Obliquely Through Both Ends of the Cylinder.**—Rule 1. Conceive the section to be continued till it meets the side of the cylinder produced; then as the difference of the versed sine of half the arcs of the two ends of the ungula is to the versed sine of half the arc of the less end, so is the height of the cylinder to the part of the side produced.

Rule 2. Find the surface of each of the ungulas, thus formed, by Case 3, and their difference will be the surface required.

Rule 3. In like manner find the solidities of each of the ungulas, and their difference will be the solidity required.

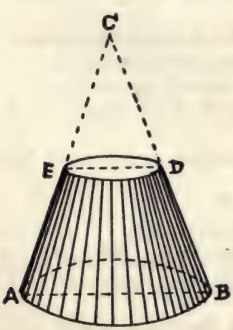


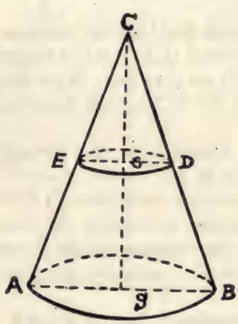




**To Find the Convex Surface of a Cone.**—Rule: Multiply the circumference of the base by the slant height, or the length of the sides of the cone, and half the product will be the surface required.

To get the complete surface of the above cone the area of the base must be added.

**The Convex Surface of a Cone is a Sector of a Circle.**—To construct such a sector: Let the circumference of the base of the cone be divided into any number of equal




parts. Then with A C as a radius describe the arc C E. Set off as many equal spaces on C E as are contained in the circumference of the base of the cone.

Draw C A and E A, the sector will equal the convex surface of the cone.

**To Find the Convex Surface of the Frustum of a Cone.**—Rule: Multiply the sum

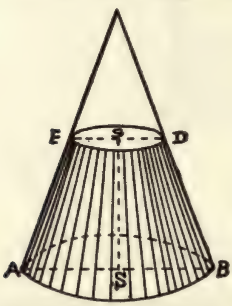
of the perimeters of the two ends by the slant height of the frustum, half the product will be the surface required.

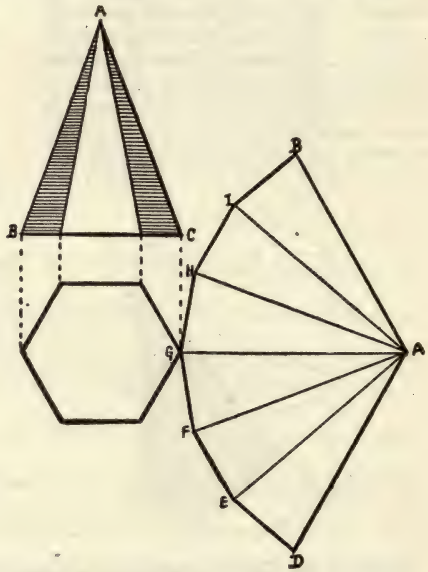
**To Find the Solidity of a Cone.**—Rule: Multiply the area of the base by one-third of the perpendicular height of the cone, the product will be the solidity.

**To Find the Solidity of a Frustum of a Cone.**—Rule: For the frustum of a cone, the diameters, or circumferences, of the two ends and the height being given. Add together the square of the diameter of the greater end, the square of the diameter of the less ends, and the product of the two diameters; multiply the sum by .7854, and the product by the height; one-third of the last product will be the solidity.

Or, add together the square of the circumference of the greater end, the square of the circumference of the less end, and the product of the two circumferences; multiply the sum by .07958, and the product by the height; one-third of the last product will be the solidity.

**To Find the Surface of a Pyramid.**




—Rule: Multiply the perimeter of the base by the length of the side, or slant height of the pyramid, and half the product will be the surface required.

Note.—By slant height is meant the distance Q O at the center of one of the slant sides. The development of the side would be a triangle A O D of which Q O is the height.

**To Develop the Convex Surface of a Pyramid.**—In this case hexagonal.

The pyramid B A C stands upon a hexagonal base, shown below it.

With A C as a radius, draw an arc, and from a central point as at G, with one of the sides of the hexagonal base as a unit, measure off three lengths to B, and three lengths to D.

Draw B A and D A, also draw through the intermediate points E, F, G, H, I, radial lines meeting in A.

Draw the perimeter lines D E, E F, F G, etc., to B.

This diagram represents the convex surface of the pyramid.

**To Find the Surface of the Frustum of a Pyramid.**—Rule: Multiply the sum of the perimeters of the ends by the slant height, and half the product will be the surface required.

Demonstration: Let A B, *a b*, represent one of the sides of the frustum of the pyramid, having the height Q *t*. By construction draw the diagonal A *b*, dividing the figure into two triangles. Let *a g* be drawn perpendicular to A *b*, and B *f* perpendicular to A *b*.

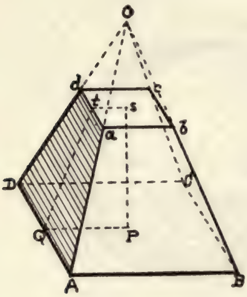
Then the triangle $A\,a\,b = \frac{1}{2}\,(A\,b \times a\,g)$, and the triangle $A\,B\,b = \frac{1}{2}\,(A\,b \times B\,f)$.

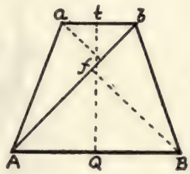
The area of the four-sided figure A *a b* B equals the area of the two triangles into

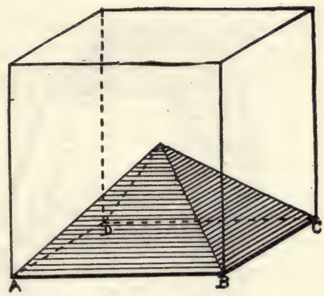
which the figure was divided by the line A $b$; therefore the area of a trapezium may be found by multiplying the sum of the parallel sides by half the perpendicular distance between them.

**To Find the Solidity of a Pyramid.**—Rule: Multiply the area of the base by one-third of the perpendicular height.

Let A B represent one edge of a cube, and lines be drawn from each of the four corners of the base A, B, C, D, to the center of the cube, a square pyramid will be



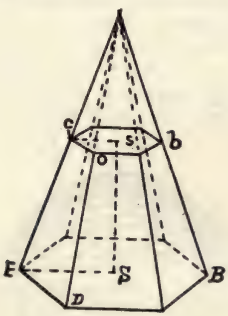



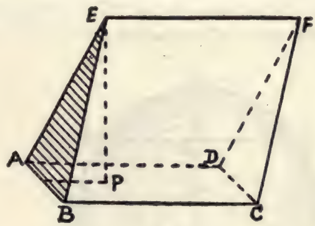

formed, the base of which will be equal to the base of the cube, and its height equal to one-half the height of the cube.

A cube consists of six sides, therefore a cube will contain six such pyramids; hence the volume of the pyramid is one-sixth that of the cube. Inasmuch as the pyramid is only one-half the height of the cube, two such pyramids can be contained within it to equal the same height; hence the volume of any pyramid is equal to $\frac{1}{3}$ (area of base $\times$ height).

**To Find the Solidity of a Frustum of a Pyramid Whose Sides Are Regular Polygons.**—Add together the square of a side of the greater end, and the square of a side of the less end, and the product of these two sides; multiply the sum by the proper number in the table under "*To find the area of a regular polygon, when the side only is given,*" and the product by the height; one-third of the last product will be the solidity.




NOTE.—When the ends of the pyramids are not regular polygons, add together the areas of the two ends and the square root of their product; multiply the sum by the height, and one-third of the product will be the solidity.




**To Find the Solidity of a Wedge.**—Rule: Add twice the length of the base to the length of the edge, and reserve the number.

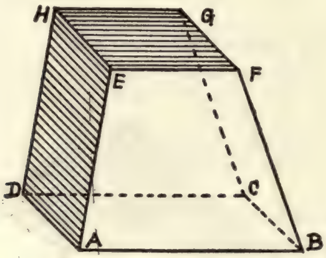
Multiply the height of the wedge by the breadth of the base, and this product by the reserved number; one-sixth of the last product will be the solidity.

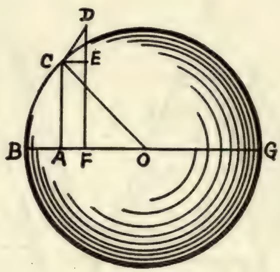
NOTE.—When the length of the base is equal to half of the wedge, the wedge is evidently equal to half a prism of the same base and altitude.

**To Find the Solidity of a Prismoid.**—Rule: To the sum of the areas of the two ends, add four times the area of a section parallel to and equally distant from both ends, and this last sum multiplied by one-sixth of the height will give the solidity.

NOTE.—The length of the middle of the rectangle is equal to half the sum of the length of the rectangle of the two ends, and its breadth equal to half the sum of the breadths of those rectangles.

**To Find the Convex Surface of a Sphere.**—Rule: Multiply the diameter of the sphere by its circumference, the product will be the convex superfices required.




NOTE.—The curve surface of any zone or segment will also be found by multiplying its height by the whole circumference of the sphere.

Cor. 1. The surface of a sphere is also equal to the curve surface of its circumscribing cylinder.

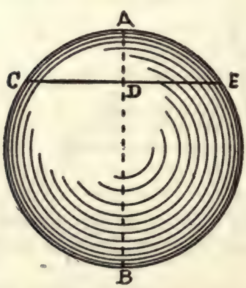
Cor. 2. The surface of a sphere is also equal to four times the area of a great circle of it.

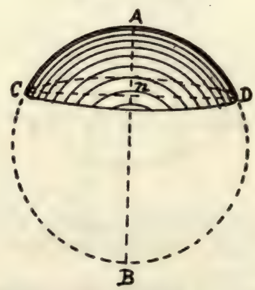
**Lunar Surface.**—To find the lunar surface included between two great circles of the sphere. Rule: Multiply the diameter into the breadth of the surface in the middle, the product will be the superfices required. Or,

as one right angle is to the great circle of the sphere,
so is the angle made by the two great circles
to the surface included by them.

**Spherical Triangle.**—To find the area of a spherical triangle, or the surface included by the intercepting arcs, of three great circles of the sphere. Rule:

As two right angles, or 180°,
is to a great circle of the sphere,
so is the excess of the three angles above two right angles
to the area of a triangle.




**To Find the Solidity of a Sphere.**—Rule: Multiply the cube of a diameter by .5236, the product will be the solidity.

Cor.—A sphere is equal to two-thirds of its circumscribing cylinder.

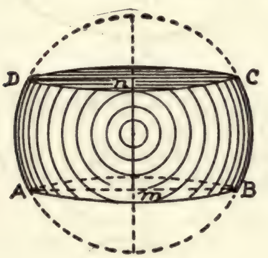
A cone, hemisphere, and cylinder of the same base and altitude are to each other ⅓, ⅔, and 1; or, as 1, 2, and 3. All spheres are to each other as the cubes of their diam-

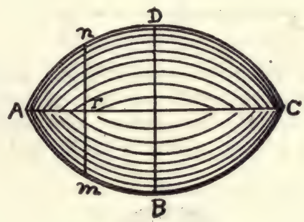
eters. For cylinders of the same altitude are to each other as the cubes of their diameters; and a sphere is two-thirds of a cylinder whose diameter and altitude are equal to the diameter of the sphere.

**To Find the Solidity of the Segment of a Sphere.**—Rule: To three times the square of the radius of its base add the square of its height; and this sum multiplied by the height, and the product again by .5236, will give the solidity. Or,

From three times the diameter of the sphere subtract twice the height of the segment, multiply by the square of the height, and that product by .5236; the last product will be the solidity.

**To Find the Solidity of a Frustum or Zone of a Sphere.**—Rule: To the sum of the squares of the radii of the two ends, add one-third of the square of their distance, or of the breadth of the zone, and this sum multiplied by the said breadth, and the product again by 1.5708, will give the solidity.




**To Find the Solidity of a Spheroid.**—Rule: Multiply the square of the revolving axe by the fixed axe, and this product again by .5236, and it will given the solidity required.

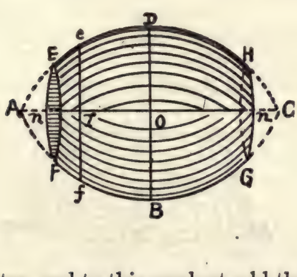
Where note that .5236 = $\frac{1}{6}$ of 3.1416.

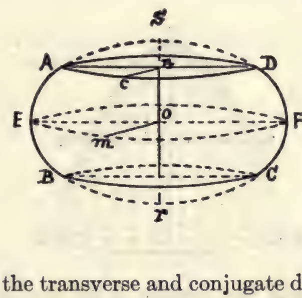
**To Find the Content of the Middle Frustum of a Spheroid, Its Length, the Middle Diameter, and That of Either of the Ends Being Given.**

**Case 1. When the Ends are Circular, or Parallel to the Revolving Axis.** Rule: To twice the square of the middle diameter, add the square of the diameter of either of the ends, and this sum multiplied by the length of the frustum, and the product again by .2618, will give the solidity.

Where note that .2618 = $\frac{1}{12}$ of 3.1416.

**Case 2. When the Ends are Elliptical or Perpendicular to the Revolving Axis.**—Rule 1. Multiply twice the transverse diameter of the middle section by its conjugate




diameter, and to this product add the product of the transverse and conjugate diameters of either of the ends.

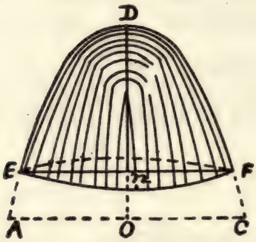
2. Multiply the sum thus found by the distance of the ends or the height of the frustum, and the product again by .2618, and it will give the solidity required.

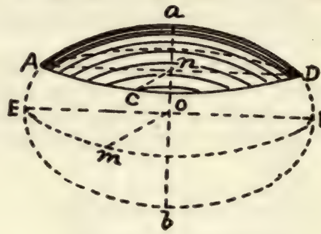
**To Find the Solidity of the Segment of a Spheroid.—Case 1. When the Base is Parallel to the Revolving Axis.**

Rule 1. Divide the square of the revolving axis by the square of the fixed axe, and multiply the quotient by the difference between three times the fixed axe and twice the height of the segment.

2. Multiply the product, thus found, by the square of the height of the segment, and this product again by .5236, and it will give the solidity required.

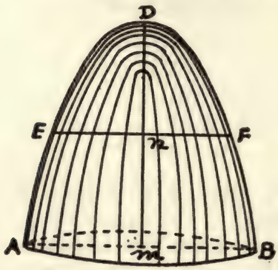
**Case 2. When the Base is Perpendicular to the Revolving Axis.**—Rule 1. Divide




the fixed axe by the revolving axe, and multiply the quotient by the difference between three times the revolving axe and twice the height of the segment.

2. Multiply the product, thus found, by the square of the height of the segment, and this product again by .5236, and it will give the solidity required.

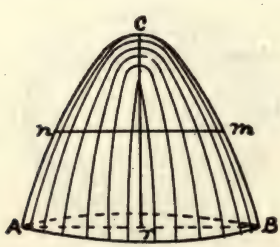


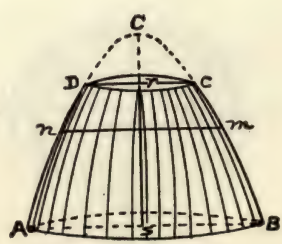


**To Find the Solidity of a Parabolic Conoid.**—Rule: Multiply the area of the base by half the altitude, and the product will be the content.

Note.—The parabolic conoid = ½ its circumscribing cylinder.

The rule given above will hold for any segment of the paraboloid, whether the base be perpendicular or oblique to the axe of the solid.




**To find the Solidity of the Frustum of a Paraboloid, When Its Ends are Perpendicular to the Axe of the Solid.**—Rule: Multiply the sum of the squares of the diameters of the two ends by the height of the frustum, and the product again by .3927, and it will give the solidity.

**To Find the Solidity of an Hyperboloid.**—Rule: To the square of the radius of the

base add the square of the middle diameter between the base and the vertex; and this sum multiplied by the altitude, and the product again by .5236 will give the solidity.

**To Find the Solidity of the Frustum of an Hyperbolic Conoid.**—Rule: Add together the squares of the greatest and least semi-diameters, and the square of the whole diameter in the middle, then this sum being multiplied by the altitude, and the product again by .5236 will give the solidity.

NOTE.—The content of any spindle formed by the revolution of a conic section about its axis may be found by the following rule:

Add together the squares of the greatest and least diameters, and square of double the diameter in the middle between the two, and this sum multiplied by the length, and the product again by .1309 will give the solidity.

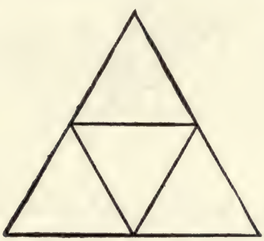
And the rule will never deviate much from the truth when the figure revolves about any other line which is not the axis.

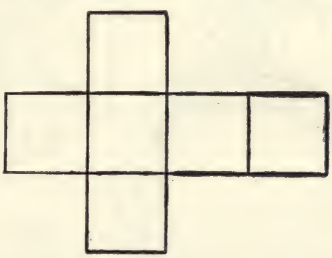
## REGULAR BODIES

The whole number of regular bodies which can possibly be formed is five:

1. The *tetrahedron*, or regular pyramid, which has four triangular faces.
2. The *hexahedron*, or cube, which has six square faces.
3. The *octahedron*, which has eight triangular faces.
4. The *dodecahedron*, which has twelve pentagonal faces.
5. The *icosahedron*, which has twenty triangular faces.

NOTE.—There are only three kinds of equilateral and equiangular plane figures which, when joined together, will form a solid angle, and these are triangles, squares,



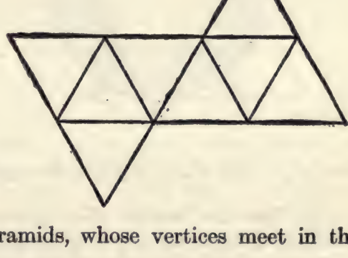


or pentagons; and there are no more than five different solids, given above, which are bounded by equilateral and equiangular plane figures.

**Tetrahedron.**—The solid angles of a tetrahedron are formed by three equilateral plane triangles, and the solid is bounded by four equal and equilateral plane triangles, therefore, it is a pyramid.

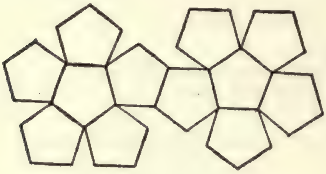
**Hexahedron.**—The solid angles of a hexahedron are formed by three equal squares, and the solid is bounded by six equal squares, therefore, it is a cube.

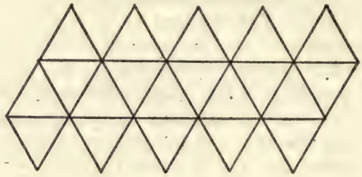
**Octahedron.**—The solid angles of an octahedron are formed by four equal and equilateral plane triangles, and the solid is bounded by eight equal and equilateral plane triangles; consequently it is formed by two equal square pyramids joined together at their bases, the sides whereof are equilateral triangles.



**Dodecahedron.**—The solid angles of a dodecahedron are formed by three equal, equilateral, and equiangular pentagons; and the solid is bounded by twelve equal, equilateral and equiangular pentagons. This solid may be conceived to consist of twelve equal pentagonal pyramids, whose vertices meet in the center of a sphere circumscribing it.

**Icosahedron.**—The solid angles of an icosahedron are formed by five equal and equilateral plane triangles, and the solid is bounded by twenty equal and equilateral plane triangles. The solid may be conceived to consist of twenty equal triangular pyramids, whose vertices meet in the center of a sphere circumscribing it.

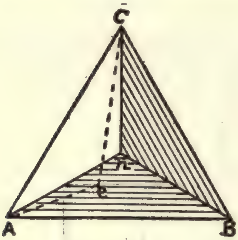


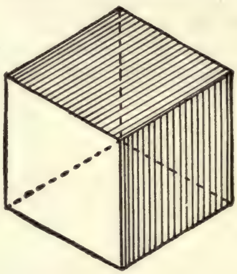


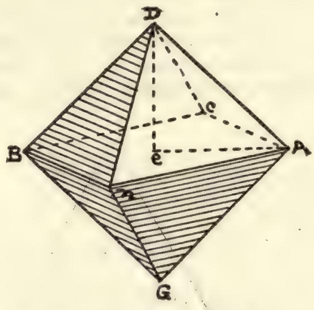
**To Find the Solidity of a Tetrahedron.**—Rule: Multiply one-twelfth of the cube of the linear side by the square root of 2, and the product will be the solidity.

**To Find the Solidity of a Hexahedron.**—Rule: Multiply the side of the cube by itself, and that product again by the side, and it will give the solidity required.

NOTE.—When the number denoting the length of the edge of the cube is known, the volume is obtained by cubing the given number.



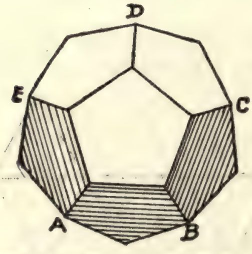



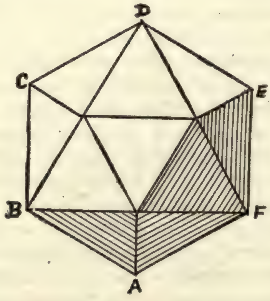



The converse operation, *i. e.*, given the volume to find the length of an edge, requires the extraction of the cube root.

**To Find the Solidity of an Octahedron.**—Rule: Multiply one-third of the cube of the linear side by the square root of 2, the product will be the solidity.

**To Find the Solidity of a Dodecahedron.**—Rule: To twenty-one times the square




root of 5, add 47, and divide the sum by 40; then the square root of the quotient being multiplied by five times the cube of the linear side will give the solidity required.

**To Find the Solidity of a Icosahedron.**—Rule: To three times the square root of 5 add 7, and divide the sum by 2; then the square root of this quotient being multiplied by five-sixths of the cube of the linear side will give the solidity required.

That is, $\frac{5}{6}S^3 \times \sqrt{\frac{(7 + 3\sqrt{5})}{2}}$ = solidity when S is = to the linear side.

NOTE.—The superfices and solidity of any of the five regular bodies may be found as follows: Rule 1. Multiply the tabular area by the square of the linear edge, and the product will be the superfices.

2. Multiply the tabular solidity by the cube of the linear edge, and the product will be the solidity.

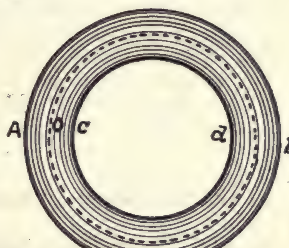
SURFACES AND SOLIDITIES OF THE REGULAR BODIES

| No. of Sides | Names | Surfaces | Solidities |
|---|---|---|---|
| 4 | Tetrahedron.......................... | 1.73205 | 0.11785 |
| 6 | Hexahedron.......................... | 6.00000 | 1.00000 |
| 8 | Octahedron.......................... | 3.46410 | 0.47140 |
| 12 | Dodecahedron.......................... | 20.64578 | 7.66312 |
| 20 | Icosahedron.......................... | 8.66025 | 2.18169 |

## CYLINDRIC RINGS

**To Find the Convex Superfices of a Cylindric Ring.**—Rule: To the thickness of the ring add the inner diameter, and this sum being multiplied by the thickness and the product again by 9.8696 will give the superfices required.

NOTE.—A solid ring of this kind is only a bent cylinder, and therefore the rules for obtaining its superfices or solidity are the same as those already given. For, let $A\,c$ be any section of the solid perpendicular to its axis $o\,n$, and then $A\,c \times 3.1416$ = circumference of that section, and $A\,c + c\,d\;(o\,n) \times 3.1416$ = length of the axis $o\,n$.




**To Find the Solidity of a Cylindric Ring.**—Rule 1. To the thickness of the ring add the inner diameter, and this sum being multiplied by the square of half the thickness and the product again by 9.8696 will give the solidity.

Rule 2. Add together the inner diameter and the thickness of the ring for a mean diameter. Multiply the mean diameter by 3.1416, and the product by the area of the cross-section of the ring will give the solidity.

## LOGARITHMS OF NUMBERS

Logarithms are useful in shortening and facilitating the arithmetical operations of multiplication and division. The sum of the logarithms of two numbers is the logarithm of the product of those numbers; and since logarithms are the indices of powers of the same basis, the difference of the logarithms of two numbers is the logarithm of the quotient; also the multiple of the logarithm of a number is the logarithm of the power of that number, and a fraction of the logarithm of a number is the logarithm of the corresponding root. Hence, a complete table of logarithms would enable one to perform multiplication by addition, division by subtraction, involution by multiplication, and evolution by division.

There are two systems of logarithms in use: The common system, in which the base is 10, and the Naperian system, in which the base (denoted by $e$) is 2.718281828. Naperian logarithms are also called *natural*, but commonly *hyperbolic* logarithms.

The common system of logarithms is generally referred to as the Briggs' system, after their inventor. In this system the logarithm of every number between 1 and 10 is some number between 0 and 1, that is, it is a fractional number. As all numbers are to be regarded as powers of 10, we have

$10^0 = 1$, and 0 is the logarithm of 1
$10^1 = 10$, and 1 is the logarithm of 10
$10^2 = 100$, and 2 is the logarithm of 100
$10^3 = 1000$, and 3 is the logarithm of 1000
$10^4 = 10000$, and 4 is the logarithm of 10000

The logarithm, therefore, of every number between 10 and 100 is some number between 1 and 2, that is, it is 1+ a fraction; similarly, every number between 100 and 1000 is some number between 2 and 3, that is, 2+ a fraction.

This principle is extended to fractions by means of negative exponents, thus

$10^{-1} = 0.1$, and $-1$ is the logarithm of 0.1
$10^{-2} = 0.01$, and $-2$ is the logarithm of 0.01
$10^{-3} = 0.001$, and $-3$ is the logarithm of 0.001
$10^{-4} = 0.0001$, and $-4$ is the logarithm of 0.0001

The logarithm of every number between 1 and 0.1 is some number between 0 and $-1$, or may be represented by $-1+$ a fraction; the logarithm of every number between 0.1 and .01 is some number between $-1$ and $-2$, or may be represented by $-2+$ a fraction, and so on. The negative sign is commonly placed over the figure, $\bar{2}$ rather than $-2$. Writing the minus sign over the characteristic, and not before it, indicates that the characteristic only is negative, and not the whole expression.

**The Logarithm of a Number Consists of Two Parts,** an integral part and a fractional part. The integral part is called the *characteristic*, and the fractional part the *mantissa.*

**The Characteristic of the Logarithm** of any number greater than unity is one less than the number of integral figures in the given number. Thus, the logarithm of 385 is 2+ a fraction; that is the characteristic of the logarithm of 385 is one less than the number of integral figures, or 2.

The characteristic of the logarithm of a decimal fraction is a negative number, and is equal to the number of places by which its first significant figure is removed from the place of units. Thus, the logarithm of .0047 is $-3+$ a fraction; that is, the characteristic of the logarithm is $-3$ ($\bar{3}$), the first significant figure 4 being removed three paces from the unit.

**To Add Two Negative Characteristics,** take their sum and make it negative. Thus $\bar{5} + \bar{2} = \bar{7}$.

**To Add a Positive to a Negative Characteristic,** take their difference and make its sign the sign of the greater; thus, $\bar{3} + 5 = 2$, and $3 + \bar{5} = \bar{2}$.

**To Subtract a Negative Characteristic,** change its sign to plus and proceed as in addition; thus, $4 - \bar{3} = 4 + 3 = 7$, and $\bar{4} - \bar{3} = \bar{4} + 3 = \bar{1}$.

**To Subtract a Positive Characteristic,** change its sign to minus and proceed as in addition; thus, $4 - 3 = 4 + \bar{3} = 1$, and $\bar{4} - 3 = \bar{4} + \bar{3} = \bar{7}$.

**To Multiply a Negative Characteristic,** multiply as if positive and make the product negative; thus, $\bar{2} \times 3 = \bar{6}$.

**The Mantissa** of a logarithm is its decimal part. The mantissa is always positive, the minus sign being usually written over the characteristic and not before it, to indicate that the characteristic only and not the whole expression is negative; thus, $\bar{1}.4084604$ stands for $-1+ .4084604$.

**Multiplication.**—The logarithm of the product of two or more factors is equal to the sum of the logarithm of those factors. If it is required to multiply two or more numbers by each other, we have only to add their logarithms: the sum will be the logarithm of their product. Then look in the table for the number answering to that logarithm and obtain the required product.

**Division.**—The logarithm of the quotient of one number divided by another is equal to the difference of the logarithm of those numbers. If it is required to divide one number by another, we have only to subtract the logarithm of the divisor from that of the dividend; the difference will be the logarithm of the quotient.

**The Decimal Part of the Logarithm** of any number is the same as that of the number multiplied or divided by 10, 100, 1000, etc. That is, if any number be multiplied or divided by 10, its logarithm will be increased or diminished by 1; and as this is an integer, it will only change the characteristic of the logarithm, without affecting the decimal part.

| | | |
|---|---|---|
| Thus, the logarithm of | 47,630 | = 4.677881 |
| | 4,763 | = 3.677881 |
| | 476.3 | = 2.677881 |
| | 47.63 | = 1.677881 |
| | 4.763 | = 0.677881 |
| | .4763 | = $\bar{1}$.677881 |
| | .04763 | = $\bar{2}$.677881 |
| | .004763 | = $\bar{3}$.677881 |

**To Divide a Logarithm Having a Negative Characteristic.**—If the characteristic is divisible by the divisor without a remainder, write the quotient with a negative sign and divide the decimal part in the usual way; $\bar{6}.458938 \div 2 = \bar{3}.229469$. If the characteristic is not divisible by the divisor without a remainder, add such a negative number to it as will make it divisible without a remainder and prefix an equal positive number to the decimal part of the logarithm, then divide the increased negative characteristic and the other part of the logarithm separately; thus

$$\bar{7}.135718 \div 3 = (\bar{2} + \bar{7} + 2.135718) \div 3 = (\bar{9} + 2.135718) \div \bar{3} = \bar{3}.711906.$$

**To Find the Logarithm of a Vulgar Fraction.**—Reduce the vulgar fraction to a decimal, and find its logarithm; or, since the value of a fraction is equal to the quotient of the numerator divided by the denominator, we may subtract the logarithm of the denominator from that of the numerator; the difference will be the logarithm of the fraction.

**Involution by Logarithm.**—On the principle that the logarithm of any power of a number is equal to the logarithm of that number multiplied by the exponent of the power, we have the following rule. Multiply the logarithm of the number by the exponent of the power required.

*Example,* required the square of 428:

| | |
|---|---|
| The logarithm of 428 is........................... | 2.631444 |
| | 2 |
| Square 183184, log............................ | 5.262888 |

It should be remembered, that what is carried from the decimal part of the logarithm, is positive, whether the characteristic is positive or negative.

*Example,* required the cube of .07654:

| | |
|---|---|
| The logarithm of .07654 is........................ | $\bar{2}$.883888 |
| | 3 |
| Cube, .0004484, log........................... | $\bar{4}$.651664 |

**Evolution by Logarithm.**—The logarithm of any root of a number is equal to the logarithm of that number divided by the index of the root. To extract the root of a number by logarithm we have the following rule:

Divide the logarithm of the number by the index of the root required.

*Example,* required the cube root of 482.38.

The logarithm of 482.38 is 2.683389.

Dividing by 3, we have 0.894463 which corresponds to 7.842, which is the root required.

When the characteristic of the logarithm is negative, and is not divisible by the given divisor, we may increase the characteristic by any number which will make it exactly divisible, provided we prefix an equal positive number to the decimal part of the logarithm.

*Example,* required the seventh root of 0.005846.

The logarithm of 0.005846 is $\bar{3}.766859$, which may be written $\bar{7} + 4.766859$.

**To Find the Reciprocal of a Number.**—Subtract the decimal part of the logarithm of the number from 0.000000; add 1 to the index of the logarithm, and change the sign of the index. This completes the logarithm of the reciprocal.

*Example,* to find the reciprocal of 230:

$$\begin{array}{lr} & 0.000000 \\ \text{Log} \quad 230 = & 2.361728 \\ \hline & \bar{3}.638272 = \text{log } 0.004348 \text{ the reciprocal.} \end{array}$$

Inversely, to find the reciprocal of the decimal .00438:

$$\begin{array}{lr} & 0.000000 \\ \text{Log } .004348 = & \bar{3}.638272 \\ \hline & 2.361728 = \text{log } 230 \text{ the reciprocal.} \end{array}$$

## TO FIND THE LOGARITHM OF A NUMBER BY THE TABLES

To find the logarithm of a number containing one or two digits, look for the number in the preliminary table, which gives all numbers from 1 to 100; the logarithm will be found in the adjoining column. For example, required the logarithm of 84. In the preliminary table, opposite 84, is 1.924279, which includes the integer. Or, annex a cipher to it, making the number 840 and find that number in the larger table; opposite will be the decimal .924279, to which is to be prefixed the integer 1, included in the preliminary table. As 84 was multiplied by 10, the base of the system, the decimal was not changed, nor would it have been if multiplied by 100, 1000, or any other multiple of 10.

The logarithm of any number between 100 and 10000 can be found in the larger table by locating the number, if less than 1000, in column N; the logarithm will be in the adjoining column under O. If the number be over 1000 and less than 10000, say 6849, find the first three of the numbers (684) in column N; in the adjoining column will be found .83, which is to be prefixed to the figures 5627, found on the same line under heading 9; the mantissa of logarithm is .835627, to which must be added the integer 3, then 3.835627 is the logarithm of 6849.

To fine the logarithm of a number consisting of five or more digits, find the logarithm for the first four as above; multiply the difference, in column D, by the remaining digits, and divide by 10, if there be only one digit more, or by 100, if there be two more, and so on; add the quotient to the logarithm for the first four. The sum is the decimal part of the required logarithm, to which the index is to be prefixed. For example, take 3.1416. The logarithm of 3141 is .497068, decimal part; and the difference 138 times 6 ÷ 10 = 83, is to be added, thus

$$\begin{array}{lr} & 0.497068 \\ & 83 \\ \hline \text{Making the complete logarithm} \ldots\ldots\ldots\ldots & 0.497151 \end{array}$$

**To Find the Number Corresponding to a Given Logarithm,** look for the logarithm without the index. If it be found exactly, or within two or three units of the right-hand digit, then the first three figures of the indicated number will be found in the number column, in a line with the logarithm, and the fourth figure at the top or the foot of the column containing the logarithm. Annex the fourth figure to the first three, and place the decimal point in its proper position, on the principles already explained. If the given logarithm differs by more than two or three units from the nearest in the table, find the number for the next less tabulated logarithm, which will give the first four digits of the required number. To find the fifth and sixth digit, subtract the tabulated logarithm from the given logarithm, add two ciphers and divide by the difference found in column D, opposite the logarithm. Annex the quotient to the four

digits already found, and place the decimal point. For example, to find the number represented by the logarithm 2.564732:

| | | |
|---|---|---|
| | | 2.564732 given logarithm, |
| Logarithm 367.0 | = | 2.564666 nearest less |
| .056 | | D 118)6600(56 nearly |
| | | 590 |
| 367.056 | | |
| | | 700 |
| | | 708 |

showing that the required number is 367.056.

## Logarithms of Numbers

From 1 to 1000

| No. | Log. | No. | Log. | No. | Log. | No. | Log. |
|---|---|---|---|---|---|---|---|
| 1 | 0.000000 | 26 | 1.414973 | 51 | 1.707570 | 76 | 1.880814 |
| 2 | 0.301030 | 27 | 1.431364 | 52 | 1.716003 | 77 | 1.886491 |
| 3 | 0.477121 | 28 | 1.447158 | 53 | 1.724276 | 78 | 1.892095 |
| 4 | 0.602060 | 29 | 1.462398 | 54 | 1.732394 | 79 | 1.897627 |
| 5 | 0.698970 | 30 | 1.477121 | 55 | 1.740363 | 80 | 1.903090 |
| 6 | 0.778151 | 31 | 1.491362 | 56 | 1.748188 | 81 | 1.908485 |
| 7 | 0.845098 | 32 | 1.505150 | 57 | 1.755875 | 82 | 1.913814 |
| 8 | 0.903090 | 33 | 1.518514 | 58 | 1.763428 | 83 | 1.919078 |
| 9 | 0.954243 | 34 | 1.531479 | 59 | 1.770852 | 84 | 1.924279 |
| 10 | 1.000000 | 35 | 1.544068 | 60 | 1.778151 | 85 | 1.929419 |
| 11 | 1.041393 | 36 | 1.556303 | 61 | 1.785330 | 86 | 1.934498 |
| 12 | 1.079181 | 37 | 1.568202 | 62 | 1.792392 | 87 | 1.939519 |
| 13 | 1.113943 | 38 | 1.579784 | 63 | 1.799341 | 88 | 1.944483 |
| 14 | 1.146128 | 39 | 1.591065 | 64 | 1.806180 | 89 | 1.949390 |
| 15 | 1.176091 | 40 | 1.602060 | 65 | 1.812913 | 90 | 1.954243 |
| 16 | 1.204120 | 41 | 1.612784 | 66 | 1.819544 | 91 | 1.959041 |
| 17 | 1.230449 | 42 | 1.623249 | 67 | 1.826075 | 92 | 1.963788 |
| 18 | 1.255273 | 43 | 1.633468 | 68 | 1.832509 | 93 | 1.968483 |
| 19 | 1.278754 | 44 | 1.643453 | 69 | 1.838849 | 94 | 1.973128 |
| 20 | 1.301030 | 45 | 1.653213 | 70 | 1.845098 | 95 | 1.977724 |
| 21 | 1.322219 | 46 | 1.662758 | 71 | 1.851258 | 96 | 1.982271 |
| 22 | 1.342423 | 47 | 1.672098 | 72 | 1.857332 | 97 | 1.986772 |
| 23 | 1.361728 | 48 | 1.681241 | 73 | 1.863323 | 98 | 1.991226 |
| 24 | 1.380211 | 49 | 1.690196 | 74 | 1.869232 | 99 | 1.995635 |
| 25 | 1.397940 | 50 | 1.698970 | 75 | 1.875061 | 100 | 2.000000 |

LOGARITHMS OF NUMBERS FROM 1 TO 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 00– | 0000 | 0434 | 0868 | 1301 | 1734 | 2166 | 2598 | 3029 | 3461 | 3891 | 432 |
| 101 | 00– | 4321 | 4751 | 5181 | 5609 | 6038 | 6466 | 6894 | 7321 | 7748 | 8174 | 428 |
| 102 | 00– | 8600 | 9026 | 9451 | 9876 | .... | .... | .... | .... | .... | .... | 425 |
| 102 | 01– | .... | .... | .... | .... | 0300 | 0724 | 1147 | 1570 | 1993 | 2415 | 424 |
| 103 | 01– | 2837 | 3259 | 3680 | 4100 | 4521 | 4940 | 5360 | 5779 | 6197 | 6616 | 420 |
| 104 | 01– | 7033 | 7451 | 7868 | 8284 | 8700 | 9116 | 9532 | 9947 | .... | .... | 417 |
| 104 | 02– | .... | .... | .... | .... | .... | .... | .... | .... | 0361 | 0775 | 416 |
| 105 | 02– | 1189 | 1603 | 2016 | 2428 | 2841 | 3252 | 3664 | 4075 | 4486 | 4896 | 412 |
| 106 | 02– | 5306 | 5715 | 6125 | 6533 | 6942 | 7350 | 7757 | 8164 | 8571 | 8978 | 408 |
| 107 | 02– | 9384 | 9789 | .... | .... | .... | .... | .... | .... | .... | .... | 405 |
| 107 | 03– | .... | .... | 0195 | 0600 | 1004 | 1408 | 1812 | 2216 | 2619 | 3021 | 404 |
| 108 | 03– | 3424 | 3826 | 4227 | 4628 | 5029 | 5430 | 5830 | 6230 | 6629 | 7028 | 400 |
| 109 | 03– | 7426 | 7825 | 8223 | 8620 | 9017 | 9414 | 9811 | .... | .... | .... | 398 |
| 109 | 04– | .... | .... | .... | .... | .... | .... | .... | 0207 | 0602 | 0998 | 397 |
| 110 | 04– | 1393 | 1787 | 2182 | 2576 | 2969 | 3362 | 3755 | 4148 | 4540 | 4932 | 393 |
| 111 | 04– | 5323 | 5714 | 6105 | 6495 | 6885 | 7275 | 7664 | 8053 | 8442 | 8830 | 389 |
| 112 | 04– | 9218 | 9606 | 9993 | .... | .... | .... | .... | .... | .... | .... | 388 |
| 112 | 05– | .... | .... | .... | 0380 | 0766 | 1153 | 1538 | 1924 | 2309 | 2694 | 386 |
| 113 | 05– | 3078 | 3463 | 3846 | 4230 | 4613 | 4996 | 5378 | 5760 | 6142 | 6524 | 383 |
| 114 | 05– | 6905 | 7286 | 7666 | 8046 | 8426 | 8805 | 9185 | 9563 | 9942 | .... | 383 |
| 114 | 06– | .... | .... | .... | .... | .... | .... | .... | .... | .... | 0320 | 379 |
| 115 | 06– | 0698 | 1075 | 1452 | 1829 | 2206 | 2582 | 2958 | 3333 | 3709 | 4083 | 376 |
| 116 | 06– | 4458 | 4832 | 5206 | 5580 | 5953 | 6326 | 6699 | 7071 | 7443 | 7815 | 373 |
| 117 | 06– | 8186 | 8557 | 8927 | 9298 | 9668 | .... | .... | .... | .... | .... | 380 |
| 117 | 07– | .... | .... | .... | .... | .... | 0038 | 0407 | 0776 | 1145 | 1514 | 370 |
| 118 | 07– | 1882 | 2250 | 2617 | 2985 | 3352 | 3718 | 4085 | 4451 | 4816 | 5182 | 366 |
| 119 | 07– | 5547 | 5912 | 6276 | 6640 | 7004 | 7368 | 7731 | 8094 | 8457 | 8819 | 363 |
| 120 | 07– | 9181 | 9543 | 9904 | .... | .... | .... | .... | .... | .... | .... | 362 |
| 120 | 08– | .... | .... | .... | 0266 | 0626 | 0987 | 1347 | 1707 | 2067 | 2426 | 360 |
| 121 | 08– | 2785 | 3144 | 3503 | 3861 | 4219 | 4576 | 4934 | 5291 | 5647 | 6004 | 357 |
| 122 | 08– | 6360 | 6716 | 7071 | 7426 | 7781 | 8136 | 8490 | 8845 | 9198 | 9552 | 355 |
| 123 | 08– | 9905 | .... | .... | .... | .... | .... | .... | .... | .... | .... | 355 |
| 123 | 09– | .... | 0258 | 0611 | 0963 | 1315 | 1667 | 2018 | 2370 | 2721 | 3071 | 353 |
| 124 | 09– | 3422 | 3772 | 4122 | 4471 | 4820 | 5169 | 5518 | 5866 | 6215 | 6562 | 349 |
| 125 | 09– | 6910 | 7257 | 7604 | 7951 | 8298 | 8644 | 8990 | 9335 | 9681 | .... | 348 |
| 125 | 10– | .... | .... | .... | .... | .... | .... | .... | .... | .... | 0026 | 346 |
| 126 | 10– | 0371 | 0715 | 1059 | 1403 | 1747 | 2091 | 2434 | 2777 | 3119 | 3462 | 343 |
| 127 | 10– | 3804 | 4146 | 4487 | 4828 | 5169 | 5510 | 5851 | 6191 | 6531 | 6871 | 341 |
| 128 | 10– | 7210 | 7549 | 7888 | 8227 | 8565 | 8903 | 9241 | 9579 | 9916 | .... | 338 |
| 128 | 11– | .... | .... | .... | .... | .... | .... | .... | .... | .... | 0253 | 337 |
| 129 | 11– | 0590 | 0926 | 1263 | 1599 | 1934 | 2270 | 2605 | 2940 | 3275 | 3609 | 335 |
| 130 | 11– | 3943 | 4277 | 4611 | 4944 | 5278 | 5611 | 5943 | 6276 | 6608 | 6940 | 333 |
| 131 | 11– | 7271 | 7603 | 7934 | 8265 | 8595 | 8926 | 9256 | 9586 | 9915 | .... | 331 |
| 131 | 12– | .... | .... | .... | .... | .... | .... | .... | .... | .... | 0245 | 330 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

LOGARITHMS OF NUMBERS FROM 1 TO 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 132 | 12– | 0574 | 0903 | 1231 | 1560 | 1888 | 2216 | 2544 | 2871 | 3198 | 3525 | 328 |
| 133 | 12– | 3852 | 4178 | 4504 | 4830 | 5156 | 5481 | 5806 | 6131 | 6456 | 6781 | 325 |
| 134 | 12– | 7105 | 7429 | 7753 | 8076 | 8399 | 8722 | 9045 | 9368 | 9690 | .... | 323 |
| 134 | 13– | .... | .... | .... | .... | .... | .... | .... | .... | .... | 0012 | 323 |
| 135 | 13– | 0334 | 0655 | 0977 | 1298 | 1619 | 1939 | 2260 | 2580 | 2900 | 3219 | 321 |
| 136 | 13– | 3539 | 3858 | 4177 | 4496 | 4814 | 5133 | 5451 | 5769 | 6086 | 6403 | 318 |
| 137 | 13– | 6721 | 7037 | 7354 | 7671 | 7987 | 8303 | 8618 | 8934 | 9249 | 9564 | 316 |
| 138 | 13– | 9879 | .... | .... | .... | .... | .... | .... | .... | .... | .... | 315 |
| 138 | 14– | .... | 0194 | 0508 | 0822 | 1136 | 1450 | 1763 | 2076 | 2389 | 2702 | 314 |
| 139 | 14– | 3015 | 3327 | 3639 | 3951 | 4263 | 4574 | 4885 | 5196 | 5507 | 5818 | 311 |
| 140 | 14– | 6128 | 6438 | 6748 | 7058 | 7367 | 7676 | 7985 | 8294 | 8603 | 8911 | 309 |
| 141 | 14– | 9219 | 9527 | 9835 | .... | .... | .... | .... | .... | .... | .... | 308 |
| 141 | 15– | .... | .... | .... | 0142 | 0449 | 0756 | 1063 | 1370 | 1676 | 1982 | 307 |
| 142 | 15– | 2288 | 2594 | 2900 | 3205 | 3510 | 3815 | 4120 | 4424 | 4728 | 5032 | 305 |
| 143 | 15– | 5336 | 5640 | 5943 | 6246 | 6549 | 6852 | 7154 | 7457 | 7759 | 8061 | 303 |
| 144 | 15– | 8362 | 8664 | 8965 | 9266 | 9567 | 9868 | .... | .... | .... | .... | 302 |
| 144 | 16– | .... | .... | .... | .... | .... | .... | 0168 | 0469 | 0769 | 1068 | 301 |
| 145 | 16– | 1368 | 1667 | 1967 | 2266 | 2564 | 2863 | 3161 | 3460 | 3758 | 4055 | 299 |
| 146 | 16– | 4353 | 4650 | 4947 | 5244 | 5541 | 5838 | 6134 | 6430 | 6726 | 7022 | 297 |
| 147 | 16– | 7317 | 7613 | 7908 | 8203 | 8497 | 8792 | 9086 | 9380 | 9674 | 9968 | 295 |
| 148 | 17– | 0262 | 0555 | 0848 | 1141 | 1434 | 1726 | 2019 | 2311 | 2603 | 2895 | 293 |
| 149 | 17– | 3186 | 3478 | 3769 | 4060 | 4351 | 4641 | 4932 | 5222 | 5512 | 5802 | 291 |
| 150 | 17– | 6091 | 6381 | 6670 | 6959 | 7248 | 7536 | 7825 | 8113 | 8401 | 8689 | 289 |
| 151 | 17– | 8977 | 9264 | 9552 | 9839 | .... | .... | .... | .... | .... | .... | 287 |
| 151 | 18– | .... | .... | .... | .... | 0126 | 0413 | 0699 | 0986 | 1272 | 1558 | 287 |
| 152 | 18– | 1844 | 2129 | 2415 | 2700 | 2985 | 3270 | 3555 | 3839 | 4123 | 4407 | 285 |
| 153 | 18– | 4691 | 4975 | 5259 | 5542 | 5825 | 6108 | 6391 | 6674 | 6956 | 7239 | 283 |
| 154 | 18– | 7521 | 7803 | 8084 | 8366 | 8647 | 8928 | 9209 | 9490 | 9771 | .... | 281 |
| 154 | 19– | .... | .... | .... | .... | .... | .... | .... | .... | .... | 0051 | 281 |
| 155 | 19– | 0332 | 0612 | 0892 | 1171 | 1451 | 1730 | 2010 | 2289 | 2567 | 2846 | 279 |
| 156 | 19– | 3125 | 3403 | 3681 | 3959 | 4237 | 4514 | 4792 | 5069 | 5346 | 5623 | 278 |
| 157 | 19– | 5900 | 6176 | 6453 | 6729 | 7005 | 7281 | 7556 | 7832 | 8107 | 8382 | 276 |
| 158 | 19– | 8657 | 8932 | 9206 | 9481 | 9755 | .... | .... | .... | .... | .... | 275 |
| 158 | 20– | .... | .... | .... | .... | .... | 0029 | 0303 | 0577 | 0850 | 1124 | 274 |
| 159 | 20– | 1397 | 1670 | 1943 | 2216 | 2488 | 2761 | 3033 | 3305 | 3577 | 3848 | 272 |
| 160 | 20– | 4120 | 4391 | 4663 | 4934 | 5204 | 5475 | 5746 | 6016 | 6286 | 6556 | 271 |
| 161 | 20– | 6826 | 7096 | 7365 | 7634 | 7904 | 8173 | 8441 | 8710 | 8979 | 9247 | 269 |
| 162 | 20– | 9515 | 9783 | .... | .... | .... | .... | .... | .... | .... | .... | 268 |
| 162 | 21– | .... | .... | 0051 | 0319 | 0586 | 0853 | 1121 | 1388 | 1654 | 1921 | 267 |
| 163 | 21– | 2188 | 2454 | 2720 | 2986 | 3252 | 3518 | 3783 | 4049 | 4314 | 4579 | 266 |
| 164 | 21– | 4844 | 5109 | 5373 | 5638 | 5902 | 6166 | 6430 | 6694 | 6957 | 7221 | 264 |
| 165 | 21– | 7484 | 7747 | 8010 | 8273 | 8536 | 8798 | 9060 | 9323 | 9585 | 9846 | 262 |
| 166 | 22– | 0108 | 0370 | 0631 | 0892 | 1153 | 1414 | 1675 | 1936 | 2196 | 2456 | 261 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

LOGARITHMS OF NUMBERS FROM 1 TO 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 167 | 22– | 2716 | 2976 | 3236 | 3496 | 3755 | 4015 | 4274 | 4533 | 4792 | 5051 | 259 |
| 168 | 22– | 5309 | 5568 | 5826 | 6084 | 6342 | 6600 | 6858 | 7115 | 7372 | 7630 | 258 |
| 169 | 22– | 7887 | 8144 | 8400 | 8657 | 8913 | 9170 | 9426 | 9682 | 9938 | .... | 257 |
| 169 | 23– | .... | .... | .... | .... | .... | .... | .... | .... | .... | 0193 | 256 |
| 170 | 23– | 0449 | 0704 | 0960 | 1215 | 1470 | 1724 | 1979 | 2234 | 2488 | 2742 | 255 |
| 171 | 23– | 2996 | 3250 | 3504 | 3757 | 4011 | 4264 | 4517 | 4770 | 5023 | 5276 | 253 |
| 172 | 23– | 5528 | 5781 | 6033 | 6285 | 6537 | 6789 | 7041 | 7292 | 7544 | 7795 | 252 |
| 173 | 23– | 8046 | 8297 | 8548 | 8799 | 9049 | 9299 | 9550 | 9800 | .... | .... | 251 |
| 173 | 24– | .... | .... | .... | .... | .... | .... | .... | .... | 0050 | 0300 | 250 |
| 174 | 24– | 0549 | 0799 | 1048 | 1297 | 1546 | 1795 | 2044 | 2293 | 2541 | 2790 | 249 |
| 175 | 24– | 3038 | 3286 | 3534 | 3782 | 4030 | 4277 | 4525 | 4772 | 5019 | 5266 | 248 |
| 176 | 24– | 5513 | 5759 | 6006 | 6252 | 6499 | 6745 | 6991 | 7237 | 7482 | 7728 | 246 |
| 177 | 24– | 7973 | 8219 | 8464 | 8709 | 8954 | 9198 | 9443 | 9687 | 9932 | .... | 246 |
| 177 | 25– | .... | .... | .... | .... | .... | .... | .... | .... | .... | 0176 | 245 |
| 178 | 25– | 0420 | 0664 | 0908 | 1151 | 1395 | 1638 | 1881 | 2125 | 2368 | 2610 | 243 |
| 179 | 25– | 2853 | 3096 | 3338 | 3580 | 3822 | 4064 | 4306 | 4548 | 4790 | 5031 | 242 |
| 180 | 25– | 5273 | 5514 | 5755 | 5996 | 6237 | 6477 | 6718 | 6958 | 7198 | 7439 | 241 |
| 181 | 25– | 7679 | 7918 | 8158 | 8398 | 8637 | 8877 | 9116 | 9355 | 9594 | 9833 | 239 |
| 182 | 26– | 0071 | 0310 | 0548 | 0787 | 1025 | 1263 | 1501 | 1739 | 1976 | 2214 | 238 |
| 183 | 26– | 2451 | 2688 | 2925 | 3162 | 3399 | 3636 | 3873 | 4109 | 4346 | 4582 | 237 |
| 184 | 26– | 4818 | 5054 | 5290 | 5525 | 5761 | 5996 | 6232 | 6467 | 6702 | 6937 | 235 |
| 185 | 26– | 7172 | 7406 | 7641 | 7875 | 8110 | 8344 | 8578 | 8812 | 9046 | 9279 | 234 |
| 186 | 26– | 9513 | 9746 | 9980 | .... | .... | .... | .... | .... | .... | .... | 234 |
| 186 | 27– | .... | .... | .... | 0213 | 0446 | 0679 | 0912 | 1144 | 1377 | 1609 | 233 |
| 187 | 27– | 1842 | 2074 | 2306 | 2538 | 2770 | 3001 | 3233 | 3464 | 3696 | 3927 | 232 |
| 188 | 27– | 4158 | 4389 | 4620 | 4850 | 5081 | 5311 | 5542 | 5772 | 6002 | 6232 | 230 |
| 189 | 27– | 6462 | 6692 | 6921 | 7151 | 7380 | 7609 | 7838 | 8067 | 8296 | 8525 | 229 |
| 190 | 27– | 8754 | 8982 | 9211 | 9439 | 9667 | 9895 | .... | .... | .... | .... | 228 |
| 190 | 28– | .... | .... | .... | .... | .... | .... | 0123 | 0351 | 0578 | 0806 | 228 |
| 191 | 28– | 1033 | 1261 | 1488 | 1715 | 1942 | 2169 | 2396 | 2622 | 2849 | 3075 | 227 |
| 192 | 28– | 3301 | 3527 | 3753 | 3979 | 4205 | 4431 | 4656 | 4882 | 5107 | 5332 | 226 |
| 193 | 28– | 5557 | 5782 | 6007 | 6232 | 6456 | 6681 | 6905 | 7130 | 7354 | 7578 | 225 |
| 194 | 28– | 7802 | 8026 | 8249 | 8473 | 8696 | 8920 | 9143 | 9366 | 9589 | 9812 | 223 |
| 195 | 29– | 0035 | 0257 | 0480 | 0702 | 0925 | 1147 | 1369 | 1591 | 1813 | 2034 | 222 |
| 196 | 29– | 2256 | 2478 | 2699 | 2920 | 3141 | 3363 | 3584 | 3804 | 4025 | 4246 | 221 |
| 197 | 29– | 4466 | 4687 | 4907 | 5127 | 5347 | 5567 | 5787 | 6007 | 6226 | 6446 | 220 |
| 198 | 29– | 6665 | 6884 | 7104 | 7323 | 7542 | 7761 | 7979 | 8198 | 8416 | 8635 | 219 |
| 199 | 29– | 8853 | 9071 | 9289 | 9507 | 9725 | 9943 | .... | .... | .... | .... | 218 |
| 199 | 30– | .... | .... | .... | .... | .... | .... | 0161 | 0378 | 0595 | 0813 | 218 |
| 200 | 30– | 1030 | 1247 | 1464 | 1681 | 1898 | 2114 | 2331 | 2547 | 2764 | 2980 | 217 |
| 201 | 30– | 3196 | 3412 | 3628 | 3844 | 4059 | 4275 | 4491 | 4706 | 4921 | 5136 | 216 |
| 202 | 30– | 5351 | 5566 | 5781 | 5996 | 6211 | 6425 | 6639 | 6854 | 7068 | 7282 | 215 |
| 203 | 30– | 7496 | 7710 | 7924 | 8137 | 8351 | 8564 | 8778 | 8991 | 9204 | 9417 | 213 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

LOGARITHMS OF NUMBERS FROM 1 TO 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 204 | 30– | 9630 | 9843 | .... | .... | .... | .... | .... | .... | .... | .... | 213 |
| 204 | 31– | .... | .... | 0056 | 0268 | 0481 | 0693 | 0906 | 1118 | 1330 | 1542 | 212 |
| 205 | 31– | 1754 | 1966 | 2177 | 2389 | 2600 | 2812 | 3023 | 3234 | 3445 | 3656 | 211 |
| 206 | 31– | 3867 | 4078 | 4289 | 4499 | 4710 | 4920 | 5130 | 5340 | 5551 | 5760 | 210 |
| 207 | 31– | 5970 | 6180 | 6390 | 6599 | 6809 | 7018 | 7227 | 7436 | 7646 | 7854 | 209 |
| 208 | 31– | 8063 | 8272 | 8481 | 8689 | 8898 | 9106 | 9314 | 9522 | 9730 | 9938 | 208 |
| 209 | 32– | 0146 | 0354 | 0562 | 0769 | 0977 | 1184 | 1391 | 1598 | 1805 | 2012 | 207 |
| 210 | 32– | 2219 | 2426 | 2633 | 2839 | 3046 | 3252 | 3458 | 3665 | 3871 | 4077 | 206 |
| 211 | 32– | 4282 | 4488 | 4694 | 4899 | 5105 | 5310 | 5516 | 5721 | 5926 | 6131 | 205 |
| 212 | 32– | 6336 | 6541 | 6745 | 6950 | 7155 | 7359 | 7563 | 7767 | 7972 | 8176 | 204 |
| 213 | 32– | 8380 | 8583 | 8787 | 8991 | 9194 | 9398 | 9601 | 9805 | .... | .... | 204 |
| 213 | 33– | .... | .... | .... | .... | .... | .... | .... | .... | 0008 | 0211 | 203 |
| 214 | 33– | 0414 | 0617 | 0819 | 1022 | 1225 | 1427 | 1630 | 1832 | 2034 | 2236 | 202 |
| 215 | 33– | 2438 | 2640 | 2842 | 3044 | 3246 | 3447 | 3649 | 3850 | 4051 | 4253 | 202 |
| 216 | 33– | 4454 | 4655 | 4856 | 5057 | 5257 | 5458 | 5658 | 5859 | 6059 | 6260 | 201 |
| 217 | 33– | 6460 | 6660 | 6860 | 7060 | 7260 | 7459 | 7659 | 7858 | 8058 | 8257 | 200 |
| 218 | 33– | 8456 | 8656 | 8855 | 9054 | 9253 | 9451 | 9650 | 9849 | .... | .... | 200 |
| 218 | 34– | .... | .... | .... | .... | .... | .... | .... | .... | 0047 | 0246 | 199 |
| 219 | 34– | 0444 | 0642 | 0841 | 1039 | 1237 | 1435 | 1632 | 1830 | 2028 | 2225 | 198 |
| 220 | 34– | 2423 | 2620 | 2817 | 3014 | 3212 | 3409 | 3606 | 3802 | 3999 | 4196 | 197 |
| 221 | 34– | 4392 | 4589 | 4785 | 4981 | 5178 | 5374 | 5570 | 5766 | 5962 | 6157 | 196 |
| 222 | 34– | 6353 | 6549 | 6744 | 6939 | 7135 | 7330 | 7525 | 7720 | 7915 | 8110 | 195 |
| 223 | 34– | 8305 | 8500 | 8694 | 8889 | 9083 | 9278 | 9472 | 9666 | 9860 | .... | 194 |
| 223 | 35– | .... | .... | .... | .... | .... | .... | .... | .... | .... | 0054 | 194 |
| 224 | 35– | 0248 | 0442 | 0636 | 0829 | 1023 | 1216 | 1410 | 1603 | 1796 | 1989 | 193 |
| 225 | 35– | 2183 | 2375 | 2568 | 2761 | 2954 | 3147 | 3339 | 3532 | 3724 | 3916 | 193 |
| 226 | 35– | 4108 | 4301 | 4493 | 4685 | 4876 | 5068 | 5260 | 5452 | 5643 | 5834 | 192 |
| 227 | 35– | 6026 | 6217 | 6408 | 6599 | 6790 | 6981 | 7172 | 7363 | 7554 | 7744 | 191 |
| 228 | 35– | 7935 | 8125 | 8316 | 8506 | 8696 | 8886 | 9076 | 9266 | 9456 | 9646 | 190 |
| 229 | 35– | 9835 | .... | .... | .... | .... | .... | .... | .... | .... | .... | 189 |
| 229 | 36– | .... | 0025 | 0215 | 0404 | 0593 | 0783 | 0972 | 1161 | 1350 | 1539 | 189 |
| 230 | 36– | 1728 | 1917 | 2105 | 2294 | 2482 | 2671 | 2859 | 3048 | 3236 | 3424 | 188 |
| 231 | 36– | 3612 | 3800 | 3988 | 4176 | 4363 | 4551 | 4739 | 4926 | 5113 | 5301 | 188 |
| 232 | 36– | 5488 | 5675 | 5862 | 6049 | 6236 | 6423 | 6610 | 6796 | 6983 | 7169 | 187 |
| 233 | 36– | 7356 | 7542 | 7729 | 7915 | 8101 | 8287 | 8473 | 8659 | 8845 | 9030 | 186 |
| 234 | 36– | 9216 | 9401 | 9587 | 9772 | 9958 | .... | .... | .... | .... | .... | 186 |
| 234 | 37– | .... | .... | .... | .... | .... | 0143 | 0328 | 0513 | 0698 | 0883 | 185 |
| 235 | 37– | 1068 | 1253 | 1437 | 1622 | 1806 | 1991 | 2175 | 2360 | 2544 | 2728 | 184 |
| 236 | 37– | 2912 | 3096 | 3280 | 3464 | 3647 | 3831 | 4015 | 4198 | 4382 | 4565 | 184 |
| 237 | 37– | 4748 | 4932 | 5115 | 5298 | 5481 | 5664 | 5846 | 6029 | 6212 | 6394 | 183 |
| 238 | 37– | 6577 | 6759 | 6942 | 7124 | 7306 | 7488 | 7670 | 7852 | 8034 | 8216 | 182 |
| 239 | 37– | 8398 | 8580 | 8761 | 8943 | 9124 | 9306 | 9487 | 9668 | 9849 | .... | 182 |
| 239 | 38– | .... | .... | .... | .... | .... | .... | .... | .... | .... | 0030 | 181 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

LOGARITHMS OF NUMBERS FROM 1 TO 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 240 | 38– | 0211 | 0392 | 0573 | 0754 | 0934 | 1115 | 1296 | 1476 | 1656 | 1837 | 181 |
| 241 | 38– | 2017 | 2197 | 2377 | 2557 | 2737 | 2917 | 3097 | 3277 | 3456 | 3636 | 180 |
| 242 | 38– | 3815 | 3995 | 4174 | 4353 | 4533 | 4712 | 4891 | 5070 | 5249 | 5428 | 179 |
| 243 | 38– | 5606 | 5785 | 5964 | 6142 | 6321 | 6499 | 6677 | 6856 | 7034 | 7212 | 178 |
| 244 | 38– | 7390 | 7568 | 7746 | 7923 | 8101 | 8279 | 8456 | 8634 | 8811 | 8989 | 178 |
| 245 | 38– | 9166 | 9343 | 9520 | 9698 | 9875 | .... | .... | .... | .... | .... | 177 |
| 245 | 39– | .... | .... | .... | .... | .... | 0051 | 0228 | 0405 | 0582 | 0759 | 177 |
| 246 | 39– | 0935 | 1112 | 1288 | 1464 | 1641 | 1817 | 1993 | 2169 | 2345 | 2521 | 176 |
| 247 | 39– | 2697 | 2873 | 3048 | 3224 | 3400 | 3575 | 3751 | 3926 | 4101 | 4277 | 176 |
| 248 | 39– | 4452 | 4627 | 4802 | 4977 | 5152 | 5326 | 5501 | 5676 | 5850 | 6025 | 175 |
| 249 | 39– | 6199 | 6374 | 6548 | 6722 | 6896 | 7071 | 7245 | 7419 | 7592 | 7766 | 174 |
| 250 | 39– | 7940 | 8114 | 8287 | 8461 | 8634 | 8808 | 8981 | 9154 | 9328 | 9501 | 173 |
| 251 | 39– | 9674 | 9847 | .... | .... | .... | .... | .... | .... | .... | .... | 173 |
| 251 | 40– | .... | .... | 0020 | 0192 | 0365 | 0538 | 0711 | 0883 | 1056 | 1228 | 173 |
| 252 | 40– | 1401 | 1573 | 1745 | 1917 | 2089 | 2261 | 2433 | 2605 | 2777 | 2949 | 172 |
| 253 | 40– | 3121 | 3292 | 3464 | 3635 | 3807 | 3978 | 4149 | 4320 | 4492 | 4663 | 171 |
| 254 | 40– | 4834 | 5005 | 5176 | 5346 | 5517 | 5688 | 5858 | 6029 | 6199 | 6370 | 171 |
| 255 | 40– | 6540 | 6710 | 6881 | 7051 | 7221 | 7391 | 7561 | 7731 | 7901 | 8070 | 170 |
| 256 | 40– | 8240 | 8410 | 8579 | 8749 | 8918 | 9087 | 9257 | 9426 | 9595 | 9764 | 169 |
| 257 | 40– | 9933 | .... | .... | .... | .... | .... | .... | .... | .... | .... | 169 |
| 257 | 41– | .... | 0102 | 0271 | 0440 | 0609 | 0777 | 0946 | 1114 | 1283 | 1451 | 169 |
| 258 | 41– | 1620 | 1788 | 1956 | 2124 | 2293 | 2461 | 2629 | 2796 | 2964 | 3132 | 168 |
| 259 | 41– | 3300 | 3467 | 3635 | 3803 | 3970 | 4137 | 4305 | 4472 | 4639 | 4806 | 167 |
| 260 | 41– | 4973 | 5140 | 5307 | 5474 | 5641 | 5808 | 5974 | 6141 | 6308 | 6474 | 167 |
| 261 | 41– | 6641 | 6807 | 6973 | 7139 | 7306 | 7472 | 7638 | 7804 | 7970 | 8135 | 166 |
| 262 | 41– | 8301 | 8467 | 8633 | 8798 | 8964 | 9129 | 9295 | 9460 | 9625 | 9791 | 165 |
| 263 | 41– | 9956 | .... | .... | .... | .... | .... | .... | .... | .... | .... | 165 |
| 263 | 42– | .... | 0121 | 0286 | 0451 | 0616 | 0781 | 0945 | 1110 | 1275 | 1439 | 165 |
| 264 | 42– | 1604 | 1768 | 1933 | 2097 | 2261 | 2426 | 2590 | 2754 | 2918 | 3082 | 164 |
| 265 | 42– | 3246 | 3410 | 3574 | 3737 | 3901 | 4065 | 4228 | 4392 | 4555 | 4718 | 164 |
| 266 | 42– | 4882 | 5045 | 5208 | 5371 | 5534 | 5697 | 5860 | 6023 | 6186 | 6349 | 163 |
| 267 | 42– | 6511 | 6674 | 6836 | 6999 | 7161 | 7324 | 7486 | 7648 | 7811 | 7973 | 162 |
| 268 | 42– | 8135 | 8297 | 8459 | 8621 | 8783 | 8944 | 9106 | 9268 | 9429 | 9591 | 162 |
| 269 | 42– | 9752 | 9914 | .... | .... | .... | .... | .... | .... | .... | .... | 162 |
| 269 | 43– | .... | .... | 0075 | 0236 | 0398 | 0559 | 0720 | 0881 | 1042 | 1203 | 161 |
| 270 | 43– | 1364 | 1525 | 1685 | 1846 | 2007 | 2167 | 2328 | 2488 | 2649 | 2809 | 161 |
| 271 | 43– | 2969 | 3130 | 3290 | 3450 | 3610 | 3770 | 3930 | 4090 | 4249 | 4409 | 160 |
| 272 | 43– | 4569 | 4729 | 4888 | 5048 | 5207 | 5367 | 5526 | 5685 | 5844 | 6004 | 159 |
| 273 | 43– | 6163 | 6322 | 6481 | 6640 | 6799 | 6957 | 7116 | 7275 | 7433 | 7592 | 159 |
| 274 | 43– | 7751 | 7909 | 8067 | 8226 | 8384 | 8542 | 8701 | 8859 | 9017 | 9175 | 158 |
| 275 | 43– | 9333 | 9491 | 9648 | 9806 | 9964 | .... | .... | .... | .... | .... | 158 |
| 275 | 44– | .... | .... | .... | .... | .... | 0122 | 0279 | 0437 | 0594 | 0752 | 158 |
| 276 | 44– | 0909 | 1066 | 1224 | 1381 | 1538 | 1695 | 1852 | 2009 | 2166 | 2323 | 157 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

LOGARITHMS OF NUMBERS FROM 1 TO 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 277 | 44– | 2480 | 2637 | 2793 | 2950 | 3106 | 3263 | 3419 | 3576 | 3732 | 3889 | 157 |
| 278 | 44– | 4045 | 4201 | 4357 | 4513 | 4669 | 4825 | 4981 | 5137 | 5293 | 5449 | 156 |
| 279 | 44– | 5604 | 5760 | 5915 | 6071 | 6226 | 6382 | 6537 | 6692 | 6848 | 7003 | 155 |
| 280 | 44– | 7158 | 7313 | 7468 | 7623 | 7778 | 7933 | 8088 | 8242 | 8397 | 8552 | 155 |
| 281 | 44– | 8706 | 8861 | 9015 | 9170 | 9324 | 9478 | 9633 | 9787 | 9941 | .... | 154 |
| 281 | 45– | .... | .... | .... | .... | .... | .... | .... | .... | .... | 0095 | 154 |
| 282 | 45– | 0249 | 0403 | 0557 | 0711 | 0865 | 1018 | 1172 | 1326 | 1479 | 1633 | 154 |
| 283 | 45– | 1786 | 1940 | 2093 | 2247 | 2400 | 2553 | 2706 | 2859 | 3012 | 3165 | 153 |
| 284 | 45– | 3318 | 3471 | 3624 | 3777 | 3930 | 4082 | 4235 | 4387 | 4540 | 4692 | 153 |
| 285 | 45– | 4845 | 4997 | 5150 | 5302 | 5454 | 5606 | 5758 | 5910 | 6062 | 6214 | 152 |
| 286 | 45– | 6366 | 6518 | 6670 | 6821 | 6973 | 7125 | 7276 | 7428 | 7579 | 7731 | 152 |
| 287 | 45– | 7882 | 8033 | 8184 | 8336 | 8487 | 8638 | 8789 | 8940 | 9091 | 9242 | 151 |
| 288 | 45– | 9392 | 9543 | 9694 | 9845 | 9995 | .... | .... | .... | .... | .... | 151 |
| 288 | 46– | .... | .... | .... | .... | .... | 0146 | 0296 | 0447 | 0597 | 0748 | 151 |
| 289 | 46– | 0898 | 1048 | 1198 | 1348 | 1499 | 1649 | 1799 | 1948 | 2098 | 2248 | 150 |
| 290 | 46– | 2398 | 2548 | 2697 | 2847 | 2997 | 3146 | 3296 | 3445 | 3594 | 3744 | 150 |
| 291 | 46– | 3893 | 4042 | 4191 | 4340 | 4490 | 4639 | 4788 | 4936 | 5085 | 5234 | 149 |
| 292 | 46– | 5383 | 5532 | 5680 | 5829 | 5977 | 6126 | 6274 | 6423 | 6571 | 6719 | 149 |
| 293 | 46– | 6868 | 7016 | 7164 | 7312 | 7460 | 7608 | 7756 | 7904 | 8052 | 8200 | 148 |
| 294 | 46– | 8347 | 8495 | 8643 | 8790 | 8938 | 9085 | 9233 | 9380 | 9527 | 9675 | 148 |
| 295 | 46– | 9822 | 9969 | .... | .... | .... | .... | .... | .... | .... | .... | 147 |
| 295 | 47– | .... | .... | 0116 | 0263 | 0410 | 0557 | 0704 | 0851 | 0998 | 1145 | 147 |
| 296 | 47– | 1292 | 1438 | 1585 | 1732 | 1878 | 2025 | 2171 | 2318 | 2464 | 2610 | 146 |
| 297 | 47– | 2756 | 2903 | 3049 | 3195 | 3341 | 3487 | 3633 | 3779 | 3925 | 4071 | 146 |
| 298 | 47– | 4216 | 4362 | 4508 | 4653 | 4799 | 4944 | 5090 | 5235 | 5381 | 5526 | 146 |
| 299 | 47– | 5671 | 5816 | 5962 | 6107 | 6252 | 6397 | 6542 | 6687 | 6832 | 6976 | 145 |
| 300 | 47– | 7121 | 7266 | 7411 | 7555 | 7700 | 7844 | 7989 | 8133 | 8278 | 8422 | 145 |
| 301 | 47– | 8566 | 8711 | 8855 | 8999 | 9143 | 9287 | 9431 | 9575 | 9719 | 9863 | 144 |
| 302 | 48– | 0007 | 0151 | 0294 | 0438 | 0582 | 0725 | 0869 | 1012 | 1156 | 1299 | 144 |
| 303 | 48– | 1443 | 1586 | 1729 | 1872 | 2016 | 2159 | 2302 | 2445 | 2588 | 2731 | 143 |
| 304 | 48– | 2874 | 3016 | 3159 | 3302 | 3445 | 3587 | 3730 | 3872 | 4015 | 4157 | 143 |
| 305 | 48– | 4300 | 4442 | 4585 | 4727 | 4869 | 5011 | 5153 | 5295 | 5437 | 5579 | 142 |
| 306 | 48– | 5721 | 5863 | 6005 | 6147 | 6289 | 6430 | 6572 | 6714 | 6855 | 6997 | 142 |
| 307 | 48– | 7138 | 7280 | 7421 | 7563 | 7704 | 7845 | 7986 | 8127 | 8269 | 8410 | 141 |
| 308 | 48– | 8551 | 8692 | 8833 | 8974 | 9114 | 9255 | 9396 | 9537 | 9677 | 9818 | 141 |
| 309 | 48– | 9958 | .... | .... | .... | .... | .... | .... | .... | .... | .... | 140 |
| 309 | 49– | .... | 0099 | 0239 | 0380 | 0520 | 0661 | 0801 | 0941 | 1081 | 1222 | 140 |
| 310 | 49– | 1362 | 1502 | 1642 | 1782 | 1922 | 2062 | 2201 | 2341 | 2481 | 2621 | 140 |
| 311 | 49– | 2760 | 2900 | 3040 | 3179 | 3319 | 3458 | 3597 | 3737 | 3876 | 4015 | 139 |
| 312 | 49– | 4155 | 4294 | 4433 | 4572 | 4711 | 4850 | 4989 | 5128 | 5267 | 5406 | 139 |
| 313 | 49– | 5544 | 5683 | 5822 | 5960 | 6099 | 6238 | 6376 | 6515 | 6653 | 6791 | 139 |
| 314 | 49– | 6930 | 7068 | 7206 | 7344 | 7483 | 7621 | 7759 | 7897 | 8035 | 8173 | 138 |
| 315 | 49– | 8311 | 8448 | 8586 | 8724 | 8862 | 8999 | 9137 | 9275 | 9412 | 9550 | 138 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

LOGARITHMS OF NUMBERS FROM 1 TO 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 316 | 49– | 9687 | 9824 | 9962 | . . . . | . . . . | . . . . | . . . . | . . . . | . . . . | . . . . | 137 |
| 316 | 50– | . . . . | . . . . | . . . . | 0099 | 0236 | 0374 | 0511 | 0648 | 0785 | 0922 | 137 |
| 317 | 50– | 1059 | 1196 | 1333 | 1470 | 1607 | 1744 | 1880 | 2017 | 2154 | 2291 | 137 |
| 318 | 50– | 2427 | 2564 | 2700 | 2837 | 2973 | 3109 | 3246 | 3382 | 3518 | 3655 | 136 |
| 319 | 50– | 3791 | 3927 | 4063 | 4199 | 4335 | 4471 | 4607 | 4743 | 4878 | 5014 | 136 |
| 320 | 50– | 5150 | 5286 | 5421 | 5557 | 5693 | 5828 | 5964 | 6099 | 6234 | 6370 | 136 |
| 321 | 50– | 6505 | 6640 | 6776 | 6911 | 7046 | 7181 | 7316 | 7451 | 7586 | 7721 | 135 |
| 322 | 50– | 7856 | 7991 | 8126 | 8260 | 8395 | 8530 | 8664 | 8799 | 8934 | 9068 | 135 |
| 323 | 50– | 9203 | 9337 | 9471 | 9606 | 9740 | 9874 | . . . . | . . . . | . . . . | . . . . | 134 |
| 323 | 51– | . . . . | . . . . | . . . . | . . . . | . . . . | . . . . | 0009 | 0143 | 0277 | 0411 | 134 |
| 324 | 51– | 0545 | 0679 | 0813 | 0947 | 1081 | 1215 | 1349 | 1482 | 1616 | 1750 | 134 |
| 325 | 51– | 1883 | 2017 | 2151 | 2284 | 2418 | 2551 | 2684 | 2818 | 2951 | 3084 | 133 |
| 326 | 51– | 3218 | 3351 | 3484 | 3617 | 3750 | 3883 | 4016 | 4149 | 4282 | 4415 | 133 |
| 327 | 51– | 4548 | 4681 | 4813 | 4946 | 5079 | 5211 | 5344 | 5476 | 5609 | 5741 | 133 |
| 328 | 51– | 5874 | 6006 | 6139 | 6271 | 6403 | 6535 | 6668 | 6800 | 6932 | 7064 | 132 |
| 329 | 51– | 7196 | 7328 | 7460 | 7592 | 7724 | 7855 | 7987 | 8119 | 8251 | 8382 | 132 |
| 330 | 51– | 8514 | 8646 | 8777 | 8909 | 9040 | 9171 | 9303 | 9434 | 9566 | 9697 | 131 |
| 331 | 51– | 9828 | 9959 | . . . . | . . . . | . . . . | . . . . | . . . . | . . . . | . . . . | . . . . | 131 |
| 331 | 52– | . . . . | . . . . | 0090 | 0221 | 0353 | 0484 | 0615 | 0745 | 0876 | 1007 | 131 |
| 332 | 52– | 1138 | 1269 | 1400 | 1530 | 1661 | 1792 | 1922 | 2053 | 2183 | 2314 | 131 |
| 333 | 52– | 2444 | 2575 | 2705 | 2835 | 2966 | 3096 | 3226 | 3356 | 3486 | 3616 | 130 |
| 334 | 52– | 3746 | 3876 | 4006 | 4136 | 4266 | 4396 | 4526 | 4656 | 4785 | 4915 | 130 |
| 335 | 52– | 5045 | 5174 | 5304 | 5434 | 5563 | 5693 | 5822 | 5951 | 6081 | 6210 | 129 |
| 336 | 52– | 6339 | 6469 | 6598 | 6727 | 6856 | 6985 | 7114 | 7243 | 7372 | 7501 | 129 |
| 337 | 52– | 7630 | 7759 | 7888 | 8016 | 8145 | 8274 | 8402 | 8531 | 8660 | 8788 | 129 |
| 338 | 52– | 8917 | 9045 | 9174 | 9302 | 9430 | 9559 | 9687 | 9815 | 9943 | . . . . | 128 |
| 338 | 53– | . . . . | . . . . | . . . . | . . . . | . . . . | . . . . | . . . . | . . . . | . . . . | 0072 | 128 |
| 339 | 53– | 0200 | 0328 | 0456 | 0584 | 0712 | 0840 | 0968 | 1096 | 1223 | 1351 | 128 |
| 340 | 53– | 1479 | 1607 | 1734 | 1862 | 1990 | 2117 | 2245 | 2372 | 2500 | 2627 | 128 |
| 341 | 53– | 2754 | 2882 | 3009 | 3136 | 3264 | 3391 | 3518 | 3645 | 3772 | 3899 | 127 |
| 342 | 53– | 4026 | 4153 | 4280 | 4407 | 4534 | 4661 | 4787 | 4914 | 5041 | 5167 | 127 |
| 343 | 53– | 5294 | 5421 | 5547 | 5674 | 5800 | 5927 | 6053 | 6180 | 6306 | 6432 | 126 |
| 344 | 53– | 6558 | 6685 | 6811 | 6937 | 7063 | 7189 | 7315 | 7441 | 7567 | 7693 | 126 |
| 345 | 53– | 7819 | 7945 | 8071 | 8197 | 8322 | 8448 | 8574 | 8699 | 8825 | 8951 | 126 |
| 346 | 53– | 9076 | 9202 | 9327 | 9452 | 9578 | 9703 | 9829 | 9954 | . . . . | . . . . | 126 |
| 346 | 54– | . . . . | . . . . | . . . . | . . . . | . . . . | . . . . | . . . . | . . . . | 0079 | 0204 | 125 |
| 347 | 54– | 0329 | 0455 | 0580 | 0705 | 0830 | 0955 | 1080 | 1205 | 1330 | 1454 | 125 |
| 348 | 54– | 1579 | 1704 | 1829 | 1953 | 2078 | 2203 | 2327 | 2452 | 2576 | 2701 | 125 |
| 349 | 54– | 2825 | 2950 | 3074 | 3199 | 3323 | 3447 | 3571 | 3696 | 3820 | 3944 | 124 |
| 350 | 54– | 4068 | 4192 | 4316 | 4440 | 4564 | 4688 | 4812 | 4936 | 5060 | 5183 | 124 |
| 351 | 54– | 5307 | 5431 | 5555 | 5678 | 5802 | 5925 | 6049 | 6172 | 6296 | 6419 | 124 |
| 352 | 54– | 6543 | 6666 | 6789 | 6913 | 7036 | 7159 | 7282 | 7405 | 7529 | 7652 | 123 |
| 353 | 54– | 7775 | 7898 | 8021 | 8144 | 8267 | 8389 | 8512 | 8635 | 8758 | 8881 | 123 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

LOGARITHMS OF NUMBERS FROM 1 TO 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 354 | 54– | 9003 | 9126 | 9249 | 9371 | 9494 | 9616 | 9739 | 9861 | 9984 | .... | 123 |
| 354 | 55– | .... | .... | .... | .... | .... | .... | .... | .... | .... | 0106 | 123 |
| 355 | 55– | 0228 | 0351 | 0473 | 0595 | 0717 | 0840 | 0962 | 1084 | 1206 | 1328 | 122 |
| 356 | 55– | 1450 | 1572 | 1694 | 1816 | 1938 | 2060 | 2181 | 2303 | 2425 | 2547 | 122 |
| 357 | 55– | 2668 | 2790 | 2911 | 3033 | 3155 | 3276 | 3398 | 3519 | 3640 | 3762 | 121 |
| 358 | 55– | 3883 | 4004 | 4126 | 4247 | 4368 | 4489 | 4610 | 4731 | 4852 | 4973 | 121 |
| 359 | 55– | 5094 | 5215 | 5336 | 5457 | 5578 | 5699 | 5820 | 5940 | 6061 | 6182 | 121 |
| 360 | 55– | 6303 | 6423 | 6544 | 6664 | 6785 | 6905 | 7026 | 7146 | 7267 | 7387 | 120 |
| 361 | 55– | 7507 | 7627 | 7748 | 7868 | 7988 | 8108 | 8228 | 8349 | 8469 | 8589 | 120 |
| 362 | 55– | 8709 | 8829 | 8948 | 9068 | 9188 | 9308 | 9428 | 9548 | 9667 | 9787 | 120 |
| 363 | 55– | 9907 | .... | .... | .... | .... | .... | .... | .... | .... | .... | 120 |
| 363 | 56– | .... | 0026 | 0146 | 0265 | 0385 | 0504 | 0624 | 0743 | 0863 | 0982 | 119 |
| 364 | 56– | 1101 | 1221 | 1340 | 1459 | 1578 | 1698 | 1817 | 1936 | 2055 | 2174 | 119 |
| 365 | 56– | 2293 | 2412 | 2531 | 2650 | 2769 | 2887 | 3006 | 3125 | 3244 | 3362 | 119 |
| 366 | 56– | 3481 | 3600 | 3718 | 3837 | 3955 | 4074 | 4192 | 4311 | 4429 | 4548 | 119 |
| 367 | 56– | 4666 | 4784 | 4903 | 5021 | 5139 | 5257 | 5376 | 5494 | 5612 | 5730 | 118 |
| 368 | 56– | 5848 | 5966 | 6084 | 6202 | 6320 | 6437 | 6555 | 6673 | 6791 | 6909 | 118 |
| 369 | 56– | 7026 | 7144 | 7262 | 7379 | 7497 | 7614 | 7732 | 7849 | 7967 | 8084 | 118 |
| 370 | 56– | 8202 | 8319 | 8436 | 8554 | 8671 | 8788 | 8905 | 9023 | 9140 | 9257 | 117 |
| 371 | 56– | 9374 | 9491 | 9608 | 9725 | 9842 | 9959 | .... | .... | .... | .... | 117 |
| 371 | 57– | .... | .... | .... | .... | .... | .... | 0076 | 0193 | 0309 | 0426 | 117 |
| 372 | 57– | 0543 | 0660 | 0776 | 0893 | 1010 | 1126 | 1243 | 1359 | 1476 | 1592 | 117 |
| 373 | 57– | 1709 | 1825 | 1942 | 2058 | 2174 | 2291 | 2407 | 2523 | 2639 | 2755 | 116 |
| 374 | 57– | 2872 | 2988 | 3104 | 3220 | 3336 | 3452 | 3568 | 3684 | 3800 | 3915 | 116 |
| 375 | 57– | 4031 | 4147 | 4263 | 4379 | 4494 | 4610 | 4726 | 4841 | 4957 | 5072 | 116 |
| 376 | 57– | 5188 | 5303 | 5419 | 5534 | 5650 | 5765 | 5880 | 5996 | 6111 | 6226 | 115 |
| 377 | 57– | 6341 | 6457 | 6572 | 6687 | 6802 | 6917 | 7032 | 7147 | 7262 | 7377 | 115 |
| 378 | 57– | 7492 | 7607 | 7722 | 7836 | 7951 | 8066 | 8181 | 8295 | 8410 | 8525 | 115 |
| 379 | 57– | 8639 | 8754 | 8868 | 8983 | 9097 | 9212 | 9326 | 9441 | 9555 | 9669 | 114 |
| 380 | 57– | 9784 | 9898 | .... | .... | .... | .... | .... | .... | .... | .... | 114 |
| 380 | 58– | .... | .... | 0012 | 0126 | 0241 | 0355 | 0469 | 0583 | 0697 | 0811 | 114 |
| 381 | 58– | 0925 | 1039 | 1153 | 1267 | 1381 | 1495 | 1608 | 1722 | 1836 | 1950 | 114 |
| 382 | 58– | 2063 | 2177 | 2291 | 2404 | 2518 | 2631 | 2745 | 2858 | 2972 | 3085 | 114 |
| 383 | 58– | 3199 | 3312 | 3426 | 3539 | 3652 | 3765 | 3879 | 3992 | 4105 | 4218 | 113 |
| 384 | 58– | 4331 | 4444 | 4557 | 4670 | 4783 | 4896 | 5009 | 5122 | 5235 | 5348 | 113 |
| 385 | 58– | 5461 | 5574 | 5686 | 5799 | 5912 | 6024 | 6137 | 6250 | 6362 | 6475 | 113 |
| 386 | 58– | 6587 | 6700 | 6812 | 6925 | 7037 | 7149 | 7262 | 7374 | 7486 | 7599 | 112 |
| 387 | 58– | 7711 | 7823 | 7935 | 8047 | 8160 | 8272 | 8384 | 8496 | 8608 | 8720 | 112 |
| 388 | 58– | 8832 | 8944 | 9056 | 9167 | 9279 | 9391 | 9503 | 9615 | 9726 | 9838 | 112 |
| 389 | 58– | 9950 | .... | .... | .... | .... | .... | .... | .... | .... | .... | 112 |
| 389 | 59– | .... | 0061 | 0173 | 0284 | 0396 | 0507 | 0619 | 0730 | 0842 | 0953 | 112 |
| 390 | 59– | 1065 | 1176 | 1287 | 1399 | 1510 | 1621 | 1732 | 1843 | 1955 | 2066 | 111 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

LOGARITHMS OF NUMBERS FROM 1 TO 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 391 | 59– | 2177 | 2288 | 2399 | 2510 | 2621 | 2732 | 2843 | 2954 | 3064 | 3175 | 111 |
| 392 | 59– | 3286 | 3397 | 3508 | 3618 | 3729 | 3840 | 3950 | 4061 | 4171 | 4282 | 111 |
| 393 | 59– | 4393 | 4503 | 4614 | 4724 | 4834 | 4945 | 5055 | 5165 | 5276 | 5386 | 110 |
| 394 | 59– | 5496 | 5606 | 5717 | 5827 | 5937 | 6047 | 6157 | 6267 | 6377 | 6487 | 110 |
| 395 | 59– | 6597 | 6707 | 6817 | 6927 | 7037 | 7146 | 7256 | 7366 | 7476 | 7586 | 110 |
| 396 | 59– | 7695 | 7805 | 7914 | 8024 | 8134 | 8243 | 8353 | 8462 | 8572 | 8681 | 110 |
| 397 | 59– | 8791 | 8900 | 9009 | 9119 | 9228 | 9337 | 9446 | 9556 | 9665 | 9774 | 109 |
| 398 | 59– | 9883 | 9992 | .... | .... | .... | .... | .... | .... | .... | .... | 109 |
| 398 | 60– | .... | .... | 0101 | 0210 | 0319 | 0428 | 0537 | 0646 | 0755 | 0864 | 109 |
| 399 | 60– | 0973 | 1082 | 1191 | 1299 | 1408 | 1517 | 1625 | 1734 | 1843 | 1951 | 109 |
| 400 | 60– | 2060 | 2169 | 2277 | 2386 | 2494 | 2603 | 2711 | 2819 | 2928 | 3036 | 108 |
| 401 | 60– | 3144 | 3253 | 3361 | 3469 | 3577 | 3686 | 3794 | 3902 | 4010 | 4118 | 108 |
| 402 | 60– | 4226 | 4334 | 4442 | 4550 | 4658 | 4766 | 4874 | 4982 | 5089 | 5197 | 108 |
| 403 | 60– | 5305 | 5413 | 5521 | 5628 | 5736 | 5844 | 5951 | 6059 | 6166 | 6274 | 108 |
| 404 | 60– | 6381 | 6489 | 6596 | 6704 | 6811 | 6919 | 7026 | 7133 | 7241 | 7348 | 107 |
| 405 | 60– | 7455 | 7562 | 7669 | 7777 | 7884 | 7991 | 8098 | 8205 | 8312 | 8419 | 107 |
| 406 | 60– | 8526 | 8633 | 8740 | 8847 | 8954 | 9061 | 9167 | 9274 | 9381 | 9488 | 107 |
| 407 | 60– | 9594 | 9701 | 9808 | 9914 | .... | .... | .... | .... | .... | .... | 107 |
| 407 | 61– | .... | .... | .... | .... | 0021 | 0128 | 0234 | 0341 | 0447 | 0554 | 107 |
| 408 | 61– | 0660 | 0767 | 0873 | 0979 | 1086 | 1192 | 1298 | 1405 | 1511 | 1617 | 106 |
| 409 | 61– | 1723 | 1829 | 1936 | 2042 | 2148 | 2254 | 2360 | 2466 | 2572 | 2678 | 106 |
| 410 | 61– | 2784 | 2890 | 2996 | 3102 | 3207 | 3313 | 3419 | 3525 | 3630 | 3736 | 106 |
| 411 | 61– | 3842 | 3947 | 4053 | 4159 | 4264 | 4370 | 4475 | 4581 | 4686 | 4792 | 106 |
| 412 | 61– | 4897 | 5003 | 5108 | 5213 | 5319 | 5424 | 5529 | 5634 | 5740 | 5845 | 105 |
| 413 | 61– | 5950 | 6055 | 6160 | 6265 | 6370 | 6476 | 6581 | 6686 | 6790 | 6895 | 105 |
| 414 | 61– | 7000 | 7105 | 7210 | 7315 | 7420 | 7525 | 7629 | 7734 | 7839 | 7943 | 105 |
| 415 | 61– | 8048 | 8153 | 8257 | 8362 | 8466 | 8571 | 8676 | 8780 | 8884 | 8989 | 105 |
| 416 | 61– | 9093 | 9198 | 9302 | 9406 | 9511 | 9615 | 9719 | 9824 | 9928 | .... | 105 |
| 416 | 62– | .... | .... | .... | .... | .... | .... | .... | .... | .... | 0032 | 104 |
| 417 | 62– | 0136 | 0240 | 0344 | 0448 | 0552 | 0656 | 0760 | 0864 | 0968 | 1072 | 104 |
| 418 | 62– | 1176 | 1280 | 1384 | 1488 | 1592 | 1695 | 1799 | 1903 | 2007 | 2110 | 104 |
| 419 | 62– | 2214 | 2318 | 2421 | 2525 | 2628 | 2732 | 2835 | 2939 | 3042 | 3146 | 104 |
| 420 | 62– | 3249 | 3353 | 3456 | 3559 | 3663 | 3766 | 3869 | 3973 | 4076 | 4179 | 103 |
| 421 | 62– | 4282 | 4385 | 4488 | 4591 | 4695 | 4798 | 4901 | 5004 | 5107 | 5210 | 103 |
| 422 | 62– | 5312 | 5415 | 5518 | 5621 | 5724 | 5827 | 5929 | 6032 | 6135 | 6238 | 103 |
| 423 | 62– | 6340 | 6443 | 6546 | 6648 | 6751 | 6853 | 6956 | 7058 | 7161 | 7263 | 103 |
| 424 | 62– | 7366 | 7468 | 7571 | 7673 | 7775 | 7878 | 7980 | 8082 | 8185 | 8287 | 102 |
| 425 | 62– | 8389 | 8491 | 8593 | 8695 | 8797 | 8900 | 9002 | 9104 | 9206 | 9308 | 102 |
| 426 | 62– | 9410 | 9512 | 9613 | 9715 | 9817 | 9919 | .... | .... | .... | .... | 102 |
| 426 | 63– | .... | .... | .... | .... | .... | .... | 0021 | 0123 | 0224 | 0326 | 102 |
| 427 | 63– | 0428 | 0530 | 0631 | 0733 | 0835 | 0936 | 1038 | 1139 | 1241 | 1342 | 102 |
| 428 | 63– | 1444 | 1545 | 1647 | 1748 | 1849 | 1951 | 2052 | 2153 | 2255 | 2356 | 101 |
| 429 | 63– | 2457 | 2559 | 2660 | 2761 | 2862 | 2963 | 3064 | 3165 | 3266 | 3367 | 101 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

Logarithms of Numbers from 1 to 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 430 | 63– | 3468 | 3569 | 3670 | 3771 | 3872 | 3973 | 4074 | 4175 | 4276 | 4376 | 101 |
| 431 | 63– | 4477 | 4578 | 4679 | 4779 | 4880 | 4981 | 5081 | 5182 | 5283 | 5383 | 101 |
| 432 | 63– | 5484 | 5584 | 5685 | 5785 | 5886 | 5986 | 6087 | 6187 | 6287 | 6388 | 100 |
| 433 | 63– | 6488 | 6588 | 6688 | 6789 | 6889 | 6989 | 7089 | 7189 | 7290 | 7390 | 100 |
| 434 | 63– | 7490 | 7590 | 7690 | 7790 | 7890 | 7990 | 8090 | 8190 | 8290 | 8389 | 100 |
| 435 | 63– | 8489 | 8589 | 8689 | 8789 | 8888 | 8988 | 9088 | 9188 | 9287 | 9387 | 100 |
| 436 | 63– | 9486 | 9586 | 9686 | 9785 | 9885 | 9984 | .... | .... | .... | .... | 100 |
| 436 | 64– | .... | .... | .... | .... | .... | .... | 0084 | 0183 | 0283 | 0382 | 99 |
| 437 | 64– | 0481 | 0581 | 0680 | 0779 | 0879 | 0978 | 1077 | 1177 | 1276 | 1375 | 99 |
| 438 | 64– | 1474 | 1573 | 1672 | 1771 | 1871 | 1970 | 2069 | 2168 | 2267 | 2366 | 99 |
| 439 | 64– | 2465 | 2563 | 2662 | 2761 | 2860 | 2959 | 3058 | 3156 | 3255 | 3354 | 99 |
| 440 | 64– | 3453 | 3551 | 3650 | 3749 | 3847 | 3946 | 4044 | 4143 | 4242 | 4340 | 99 |
| 441 | 64– | 4439 | 4537 | 4636 | 4734 | 4832 | 4931 | 5029 | 5127 | 5226 | 5324 | 98 |
| 442 | 64– | 5422 | 5521 | 5619 | 5717 | 5815 | 5913 | 6011 | 6110 | 6208 | 6306 | 98 |
| 443 | 64– | 6404 | 6502 | 6600 | 6698 | 6796 | 6894 | 6992 | 7089 | 7187 | 7285 | 98 |
| 444 | 64– | 7383 | 7481 | 7579 | 7676 | 7774 | 7872 | 7969 | 8067 | 8165 | 8262 | 98 |
| 445 | 64– | 8360 | 8458 | 8555 | 8653 | 8750 | 8848 | 8945 | 9043 | 9140 | 9237 | 97 |
| 446 | 64– | 9335 | 9432 | 9530 | 9627 | 9724 | 9821 | 9919 | .... | .... | .... | 97 |
| 446 | 65– | .... | .... | .... | .... | .... | .... | .... | 0016 | 0113 | 0210 | 97 |
| 447 | 65– | 0308 | 0405 | 0502 | 0599 | 0696 | 0793 | 0890 | 0987 | 1084 | 1181 | 97 |
| 448 | 65– | 1278 | 1375 | 1472 | 1569 | 1666 | 1762 | 1859 | 1956 | 2053 | 2150 | 97 |
| 449 | 65– | 2246 | 2343 | 2440 | 2536 | 2633 | 2730 | 2826 | 2923 | 3019 | 3116 | 97 |
| 450 | 65– | 3213 | 3309 | 3405 | 3502 | 3598 | 3695 | 3791 | 3888 | 3984 | 4080 | 96 |
| 451 | 65– | 4177 | 4273 | 4369 | 4465 | 4562 | 4658 | 4754 | 4850 | 4946 | 5042 | 96 |
| 452 | 65– | 5138 | 5235 | 5331 | 5427 | 5523 | 5619 | 5715 | 5810 | 5906 | 6002 | 96 |
| 453 | 65– | 6098 | 6194 | 6290 | 6386 | 6482 | 6577 | 6673 | 6769 | 6864 | 6960 | 96 |
| 454 | 65– | 7056 | 7152 | 7247 | 7343 | 7438 | 7534 | 7629 | 7725 | 7820 | 7916 | 96 |
| 455 | 65– | 8011 | 8107 | 8202 | 8298 | 8393 | 8488 | 8584 | 8679 | 8774 | 8870 | 95 |
| 456 | 65– | 8965 | 9060 | 9155 | 9250 | 9346 | 9441 | 9536 | 9631 | 9726 | 9821 | 95 |
| 457 | 65– | 9916 | .... | .... | .... | .... | .... | .... | .... | .... | .... | 95 |
| 457 | 66– | .... | 0011 | 0106 | 0201 | 0296 | 0391 | 0486 | 0581 | 0676 | 0771 | 95 |
| 458 | 66– | 0865 | 0960 | 1055 | 1150 | 1245 | 1339 | 1434 | 1529 | 1623 | 1718 | 95 |
| 459 | 66– | 1813 | 1907 | 2002 | 2096 | 2191 | 2286 | 2380 | 2475 | 2569 | 2663 | 95 |
| 460 | 66– | 2758 | 2852 | 2947 | 3041 | 3135 | 3230 | 3324 | 3418 | 3512 | 3607 | 94 |
| 461 | 66– | 3701 | 3795 | 3889 | 3983 | 4078 | 4172 | 4266 | 4360 | 4454 | 4548 | 94 |
| 462 | 66– | 4642 | 4736 | 4830 | 4924 | 5018 | 5112 | 5206 | 5299 | 5393 | 5487 | 94 |
| 463 | 66– | 5581 | 5675 | 5769 | 5862 | 5956 | 6050 | 6143 | 6237 | 6331 | 6424 | 94 |
| 464 | 66– | 6518 | 6612 | 6705 | 6799 | 6892 | 6986 | 7079 | 7173 | 7266 | 7360 | 94 |
| 465 | 66– | 7453 | 7546 | 7640 | 7733 | 7826 | 7920 | 8013 | 8106 | 8199 | 8293 | 93 |
| 466 | 66– | 8386 | 8479 | 8572 | 8665 | 8759 | 8852 | 8945 | 9038 | 9131 | 9224 | 93 |
| 467 | 66– | 9317 | 9410 | 9503 | 9596 | 9689 | 9782 | 9875 | 9967 | .... | .... | 93 |
| 467 | 67– | .... | .... | .... | .... | .... | .... | .... | .... | 0060 | 0153 | 93 |
| 468 | 67– | 0246 | 0339 | 0431 | 0524 | 0617 | 0710 | 0802 | 0895 | 0988 | 1080 | 93 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

LOGARITHMS OF NUMBERS FROM 1 TO 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 469 | 67– | 1173 | 1265 | 1358 | 1451 | 1543 | 1636 | 1728 | 1821 | 1913 | 2005 | 93 |
| 470 | 67– | 2098 | 2190 | 2283 | 2375 | 2467 | 2560 | 2652 | 2744 | 2836 | 2929 | 92 |
| 471 | 67– | 3021 | 3113 | 3205 | 3297 | 3390 | 3482 | 3574 | 3666 | 3758 | 3850 | 92 |
| 472 | 67– | 3942 | 4034 | 4126 | 4218 | 4310 | 4402 | 4494 | 4586 | 4677 | 4769 | 92 |
| 473 | 67– | 4861 | 4953 | 5045 | 5137 | 5228 | 5320 | 5412 | 5503 | 5595 | 5687 | 92 |
| 474 | 67– | 5778 | 5870 | 5962 | 6053 | 6145 | 6236 | 6328 | 6419 | 6511 | 6602 | 92 |
| 475 | 67– | 6694 | 6785 | 6876 | 6968 | 7059 | 7151 | 7242 | 7333 | 7424 | 7516 | 91 |
| 476 | 67– | 7607 | 7698 | 7789 | 7881 | 7972 | 8063 | 8154 | 8245 | 8336 | 8427 | 91 |
| 477 | 67– | 8518 | 8609 | 8700 | 8791 | 8882 | 8973 | 9064 | 9155 | 9246 | 9337 | 91 |
| 478 | 67– | 9428 | 9519 | 9610 | 9700 | 9791 | 9882 | 9973 | .... | .... | .... | 91 |
| 478 | 68– | .... | .... | .... | .... | .... | .... | .... | 0063 | 0154 | 0245 | 91 |
| 479 | 68– | 0336 | 0426 | 0517 | 0607 | 0698 | 0789 | 0879 | 0970 | 1060 | 1151 | 91 |
| 480 | 68– | 1241 | 1332 | 1422 | 1513 | 1603 | 1693 | 1784 | 1874 | 1964 | 2055 | 90 |
| 481 | 68– | 2145 | 2235 | 2326 | 2416 | 2506 | 2596 | 2686 | 2777 | 2867 | 2957 | 90 |
| 482 | 68– | 3047 | 3137 | 3227 | 3317 | 3407 | 3497 | 3587 | 3677 | 3767 | 3857 | 90 |
| 483 | 68– | 3947 | 4037 | 4127 | 4217 | 4307 | 4396 | 4486 | 4576 | 4666 | 4756 | 90 |
| 484 | 68– | 4845 | 4935 | 5025 | 5114 | 5204 | 5294 | 5383 | 5473 | 5563 | 5652 | 90 |
| 485 | 68– | 5742 | 5831 | 5921 | 6010 | 6100 | 6189 | 6279 | 6368 | 6458 | 6547 | 89 |
| 486 | 68– | 6636 | 6726 | 6815 | 6904 | 6994 | 7083 | 7172 | 7261 | 7351 | 7440 | 89 |
| 487 | 68– | 7529 | 7618 | 7707 | 7796 | 7886 | 7975 | 8064 | 8153 | 8242 | 8331 | 89 |
| 488 | 68– | 8420 | 8509 | 8598 | 8687 | 8776 | 8865 | 8953 | 9042 | 9131 | 9220 | 89 |
| 489 | 68– | 9309 | 9398 | 9486 | 9575 | 9664 | 9753 | 9841 | 9930 | .... | .... | 89 |
| 489 | 69– | .... | .... | .... | .... | .... | .... | .... | .... | 0019 | 0107 | 89 |
| 490 | 69– | 0196 | 0285 | 0373 | 0462 | 0550 | 0639 | 0728 | 0816 | 0905 | 0993 | 89 |
| 491 | 69– | 1081 | 1170 | 1258 | 1347 | 1435 | 1524 | 1612 | 1700 | 1789 | 1877 | 88 |
| 492 | 69– | 1965 | 2053 | 2142 | 2230 | 2318 | 2406 | 2494 | 2583 | 2671 | 2759 | 88 |
| 493 | 69– | 2847 | 2935 | 3023 | 3111 | 3199 | 3287 | 3375 | 3463 | 3551 | 3639 | 88 |
| 494 | 69– | 3727 | 3815 | 3903 | 3991 | 4078 | 4166 | 4254 | 4342 | 4430 | 4517 | 88 |
| 495 | 69– | 4605 | 4693 | 4781 | 4868 | 4956 | 5044 | 5131 | 5219 | 5307 | 5394 | 88 |
| 496 | 69– | 5482 | 5569 | 5657 | 5744 | 5832 | 5919 | 6007 | 6094 | 6182 | 6269 | 87 |
| 497 | 69– | 6356 | 6444 | 6531 | 6618 | 6706 | 6793 | 6880 | 6968 | 7055 | 7142 | 87 |
| 498 | 69– | 7229 | 7317 | 7404 | 7491 | 7578 | 7665 | 7752 | 7839 | 7926 | 8014 | 87 |
| 499 | 69– | 8101 | 8188 | 8275 | 8362 | 8449 | 8535 | 8622 | 8709 | 8796 | 8883 | 87 |
| 500 | 69– | 8970 | 9057 | 9144 | 9231 | 9317 | 9404 | 9491 | 9578 | 9664 | 9751 | 87 |
| 501 | 69– | 9838 | 9924 | .... | .... | .... | .... | .... | .... | .... | .... | 87 |
| 501 | 70– | .... | .... | 0011 | 0098 | 0184 | 0271 | 0358 | 0444 | 0531 | 0617 | 87 |
| 502 | 70– | 0704 | 0790 | 0877 | 0963 | 1050 | 1136 | 1222 | 1309 | 1395 | 1482 | 86 |
| 503 | 70– | 1568 | 1654 | 1741 | 1827 | 1913 | 1999 | 2086 | 2172 | 2258 | 2344 | 86 |
| 504 | 70– | 2431 | 2517 | 2603 | 2689 | 2775 | 2861 | 2947 | 3033 | 3119 | 3205 | 86 |
| 505 | 70– | 3291 | 3377 | 3463 | 3549 | 3635 | 3721 | 3807 | 3893 | 3979 | 4065 | 86 |
| 506 | 70– | 4151 | 4236 | 4322 | 4408 | 4494 | 4579 | 4665 | 4751 | 4837 | 4922 | 86 |
| 507 | 70– | 5008 | 5094 | 5179 | 5265 | 5350 | 5436 | 5522 | 5607 | 5693 | 5778 | 86 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

LOGARITHMS OF NUMBERS FROM 1 TO 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 508 | 70– | 5864 | 5949 | 6035 | 6120 | 6206 | 6291 | 6376 | 6462 | 6547 | 6632 | 85 |
| 509 | 70– | 6718 | 6803 | 6888 | 6974 | 7059 | 7144 | 7229 | 7315 | 7400 | 7485 | 85 |
| 510 | 70– | 7570 | 7655 | 7740 | 7826 | 7911 | 7996 | 8081 | 8166 | 8251 | 8336 | 85 |
| 511 | 70– | 8421 | 8506 | 8591 | 8676 | 8761 | 8846 | 8931 | 9015 | 9100 | 9185 | 85 |
| 512 | 70– | 9270 | 9355 | 9440 | 9524 | 9609 | 9694 | 9779 | 9863 | 9948 | .... | 85 |
| 512 | 71– | .... | .... | .... | .... | .... | .... | .... | .... | .... | 0033 | 85 |
| 513 | 71– | 0117 | 0202 | 0287 | 0371 | 0456 | 0540 | 0625 | 0710 | 0794 | 0879 | 85 |
| 514 | 71– | 0963 | 1048 | 1132 | 1217 | 1301 | 1385 | 1470 | 1554 | 1639 | 1723 | 84 |
| 515 | 71– | 1807 | 1892 | 1976 | 2060 | 2144 | 2229 | 2313 | 2397 | 2481 | 2566 | 84 |
| 516 | 71– | 2650 | 2734 | 2818 | 2902 | 2986 | 3070 | 3154 | 3238 | 3323 | 3407 | 84 |
| 517 | 71– | 3491 | 3575 | 3659 | 3742 | 3826 | 3910 | 3994 | 4078 | 4162 | 4246 | 84 |
| 518 | 71– | 4330 | 4414 | 4497 | 4581 | 4665 | 4749 | 4833 | 4916 | 5000 | 5084 | 84 |
| 519 | 71– | 5167 | 5251 | 5335 | 5418 | 5502 | 5586 | 5669 | 5753 | 5836 | 5920 | 84 |
| 520 | 71– | 6003 | 6087 | 6170 | 6254 | 6337 | 6421 | 6504 | 6588 | 6671 | 6754 | 83 |
| 521 | 71– | 6838 | 6921 | 7004 | 7088 | 7171 | 7254 | 7338 | 7421 | 7504 | 7587 | 83 |
| 522 | 71– | 7671 | 7754 | 7837 | 7920 | 8003 | 8086 | 8169 | 8253 | 8336 | 8419 | 83 |
| 523 | 71– | 8502 | 8585 | 8668 | 8751 | 8834 | 8917 | 9000 | 9083 | 9165 | 9248 | 83 |
| 524 | 71– | 9331 | 9414 | 9497 | 9580 | 9663 | 9745 | 9828 | 9911 | 9994 | .... | 83 |
| 524 | 72– | .... | .... | .... | .... | .... | .... | .... | .... | .... | 0077 | 83 |
| 525 | 72– | 0159 | 0242 | 0325 | 0407 | 0490 | 0573 | 0655 | 0738 | 0821 | 0903 | 83 |
| 526 | 72– | 0986 | 1068 | 1151 | 1233 | 1316 | 1398 | 1481 | 1563 | 1646 | 1728 | 82 |
| 527 | 72– | 1811 | 1893 | 1975 | 2058 | 2140 | 2222 | 2305 | 2387 | 2469 | 2552 | 82 |
| 528 | 72– | 2634 | 2716 | 2798 | 2881 | 2963 | 3045 | 3127 | 3209 | 3291 | 3374 | 82 |
| 529 | 72– | 3456 | 3538 | 3620 | 3702 | 3784 | 3866 | 3948 | 4030 | 4112 | 4194 | 82 |
| 530 | 72– | 4276 | 4358 | 4440 | 4522 | 4604 | 4685 | 4767 | 4849 | 4931 | 5013 | 82 |
| 531 | 72– | 5095 | 5176 | 5258 | 5340 | 5422 | 5503 | 5585 | 5667 | 5748 | 5830 | 82 |
| 532 | 72– | 5912 | 5993 | 6075 | 6165 | 6238 | 6320 | 6401 | 6483 | 6564 | 6646 | 82 |
| 533 | 72– | 6727 | 6809 | 6890 | 6972 | 7053 | 7134 | 7216 | 7297 | 7379 | 7460 | 81 |
| 534 | 72– | 7541 | 7623 | 7704 | 7785 | 7866 | 7948 | 8029 | 8110 | 8191 | 8273 | 81 |
| 535 | 72– | 8354 | 8435 | 8516 | 8597 | 8678 | 8759 | 8841 | 8922 | 9003 | 9084 | 81 |
| 536 | 72– | 9165 | 9246 | 9327 | 9408 | 9489 | 9570 | 9651 | 9732 | 9813 | 9893 | 81 |
| 537 | 72– | 9974 | .... | .... | .... | .... | .... | .... | .... | .... | .... | 81 |
| 537 | 73– | .... | 0055 | 0136 | 0217 | 0298 | 0378 | 0459 | 0540 | 0621 | 0702 | 81 |
| 538 | 73– | 0782 | 0863 | 0944 | 1024 | 1105 | 1186 | 1266 | 1347 | 1428 | 1508 | 81 |
| 539 | 73– | 1589 | 1669 | 1750 | 1830 | 1911 | 1991 | 2072 | 2152 | 2233 | 2313 | 81 |
| | | | | | | | | | | | | 80 |
| 540 | 73– | 2394 | 2474 | 2555 | 2635 | 2715 | 2796 | 2876 | 2956 | 3037 | 3117 | 80 |
| 541 | 73– | 3197 | 3278 | 3358 | 3438 | 3518 | 3598 | 3679 | 3759 | 3839 | 3919 | 80 |
| 542 | 73– | 3999 | 4079 | 4160 | 4240 | 4320 | 4400 | 4480 | 4560 | 4640 | 4720 | 80 |
| 543 | 73– | 4800 | 4880 | 4960 | 5040 | 5120 | 5200 | 5279 | 5359 | 5439 | 5519 | 80 |
| 544 | 73– | 5599 | 5679 | 5759 | 5838 | 5918 | 5998 | 6078 | 6157 | 6237 | 6317 | 80 |
| 545 | 73– | 6397 | 6476 | 6556 | 6635 | 6715 | 6795 | 6874 | 6954 | 7034 | 7113 | 80 |
| 546 | 73– | 7193 | 7272 | 7352 | 7431 | 7511 | 7590 | 7670 | 7749 | 7829 | 7908 | 79 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

Logarithms of Numbers from 1 to 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 547 | 73– | 7987 | 8067 | 8146 | 8225 | 8305 | 8384 | 8463 | 8543 | 8622 | 8701 | 79 |
| 548 | 73– | 8781 | 8860 | 8939 | 9018 | 9097 | 9177 | 9256 | 9335 | 9414 | 9493 | 79 |
| 549 | 73– | 9572 | 9651 | 9731 | 9810 | 9889 | 9968 | .... | .... | .... | .... | 79 |
| 549 | 74– | .... | .... | .... | .... | .... | .... | 0047 | 0126 | 0205 | 0284 | 79 |
| 550 | 74– | 0363 | 0442 | 0521 | 0600 | 0678 | 0757 | 0836 | 0915 | 0994 | 1073 | 79 |
| 551 | 74– | 1152 | 1230 | 1309 | 1388 | 1467 | 1546 | 1624 | 1703 | 1782 | 1860 | 79 |
| 552 | 74– | 1939 | 2018 | 2096 | 2175 | 2254 | 2332 | 2411 | 2489 | 2568 | 2647 | 79 |
| 553 | 74– | 2725 | 2804 | 2882 | 2961 | 3039 | 3118 | 3196 | 3275 | 3353 | 3431 | 78 |
| 554 | 74– | 3510 | 3588 | 3667 | 3745 | 3823 | 3902 | 3980 | 4058 | 4136 | 4215 | 78 |
| 555 | 74– | 4293 | 4371 | 4449 | 4528 | 4606 | 4684 | 4762 | 4840 | 4919 | 4997 | 78 |
| 556 | 74– | 5075 | 5153 | 5231 | 5309 | 5387 | 5465 | 5543 | 5621 | 5699 | 5777 | 78 |
| 557 | 74– | 5855 | 5933 | 6011 | 6089 | 6167 | 6245 | 6323 | 6401 | 6479 | 6556 | 78 |
| 558 | 74– | 6634 | 6712 | 6790 | 6868 | 6945 | 7023 | 7101 | 7179 | 7256 | 7334 | 78 |
| 559 | 74– | 7412 | 7489 | 7567 | 7645 | 7722 | 7800 | 7878 | 7955 | 8033 | 8110 | 78 |
| 560 | 74– | 8188 | 8266 | 8343 | 8421 | 8498 | 8576 | 8653 | 8731 | 8808 | 8885 | 77 |
| 561 | 74– | 8963 | 9040 | 9118 | 9195 | 9272 | 9350 | 9427 | 9504 | 9582 | 9659 | 77 |
| 562 | 74– | 9736 | 9814 | 9891 | 9968 | .... | .... | .... | .... | .... | .... | 77 |
| 562 | 75– | .... | .... | .... | .... | 0045 | 0123 | 0200 | 0277 | 0354 | 0431 | 77 |
| 563 | 75– | 0508 | 0586 | 0663 | 0740 | 0817 | 0894 | 0971 | 1048 | 1125 | 1202 | 77 |
| 564 | 75– | 1279 | 1356 | 1433 | 1510 | 1587 | 1664 | 1741 | 1818 | 1895 | 1972 | 77 |
| 565 | 75– | 2048 | 2125 | 2202 | 2279 | 2356 | 2433 | 2509 | 2586 | 2663 | 2740 | 77 |
| 566 | 75– | 2816 | 2893 | 2970 | 3047 | 3123 | 3200 | 3277 | 3353 | 3430 | 3506 | 77 |
| 567 | 75– | 3583 | 3660 | 3736 | 3813 | 3889 | 3966 | 4042 | 4119 | 4195 | 4272 | 77 |
| 568 | 75– | 4348 | 4425 | 4501 | 4578 | 4654 | 4730 | 4807 | 4883 | 4960 | 5036 | 76 |
| 569 | 75– | 5112 | 5189 | 5265 | 5341 | 5417 | 5494 | 5570 | 5646 | 5722 | 5799 | 76 |
| 570 | 75– | 5875 | 5951 | 6027 | 6103 | 6180 | 6256 | 6332 | 6408 | 6484 | 6560 | 76 |
| 571 | 75– | 6636 | 6712 | 6788 | 6864 | 6940 | 7016 | 7092 | 7168 | 7244 | 7320 | 76 |
| 572 | 75– | 7396 | 7472 | 7548 | 7624 | 7700 | 7775 | 7851 | 7927 | 8003 | 8079 | 76 |
| 573 | 75– | 8155 | 8230 | 8306 | 8382 | 8458 | 8533 | 8609 | 8685 | 8761 | 8836 | 76 |
| 574 | 75– | 8912 | 8988 | 9063 | 9139 | 9214 | 9290 | 9366 | 9441 | 9517 | 9592 | 76 |
| 575 | 75– | 9668 | 9743 | 9819 | 9894 | 9970 | .... | .... | .... | .... | .... | 76 |
| 575 | 76– | .... | .... | .... | .... | .... | 0045 | 0121 | 0196 | 0272 | 0347 | 75 |
| 576 | 76– | 0422 | 0498 | 0573 | 0649 | 0724 | 0799 | 0875 | 0950 | 1025 | 1101 | 75 |
| 577 | 76– | 1176 | 1251 | 1326 | 1402 | 1477 | 1552 | 1627 | 1702 | 1778 | 1853 | 75 |
| 578 | 76– | 1928 | 2003 | 2078 | 2153 | 2228 | 2303 | 2378 | 2453 | 2529 | 2604 | 75 |
| 579 | 76– | 2679 | 2754 | 2829 | 2904 | 2978 | 3053 | 3128 | 3203 | 3278 | 3353 | 75 |
| 580 | 76– | 3428 | 3503 | 3578 | 3653 | 3727 | 3802 | 3877 | 3952 | 4027 | 4101 | 75 |
| 581 | 76– | 4176 | 4251 | 4326 | 4400 | 4475 | 4550 | 4624 | 4699 | 4774 | 4848 | 75 |
| 582 | 76– | 4923 | 4998 | 5072 | 5147 | 5221 | 5296 | 5370 | 5445 | 5520 | 5594 | 75 |
| 583 | 76– | 5669 | 5743 | 5818 | 5892 | 5966 | 6041 | 6115 | 6190 | 6264 | 6338 | 74 |
| 584 | 76– | 6413 | 6487 | 6562 | 6636 | 6710 | 6785 | 6859 | 6933 | 7007 | 7082 | 74 |
| 585 | 76– | 7156 | 7230 | 7304 | 7379 | 7453 | 7527 | 7601 | 7675 | 7749 | 7823 | 74 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

LOGARITHMS OF NUMBERS FROM 1 TO 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 586 | 76– | 7898 | 7972 | 8046 | 8120 | 8194 | 8268 | 8342 | 8416 | 8490 | 8564 | 74 |
| 587 | 76– | 8638 | 8712 | 8786 | 8860 | 8934 | 9008 | 9082 | 9156 | 9230 | 9303 | 74 |
| 588 | 76– | 9377 | 9451 | 9525 | 9599 | 9673 | 9746 | 9820 | 9894 | 9968 | .... | 74 |
| 588 | 77– | .... | .... | .... | .... | .... | .... | .... | .... | .... | 0042 | 74 |
| 589 | 77– | 0115 | 0189 | 0263 | 0336 | 0410 | 0484 | 0557 | 0631 | 0705 | 0778 | 74 |
| 590 | 77– | 0852 | 0926 | 0999 | 1073 | 1146 | 1220 | 1293 | 1367 | 1440 | 1514 | 74 |
| 591 | 77– | 1587 | 1661 | 1734 | 1808 | 1881 | 1955 | 2028 | 2102 | 2175 | 2248 | 73 |
| 592 | 77– | 2322 | 2395 | 2468 | 2542 | 2615 | 2688 | 2762 | 2835 | 2908 | 2981 | 73 |
| 593 | 77– | 3055 | 3128 | 3201 | 3274 | 3348 | 3421 | 3494 | 3567 | 3640 | 3713 | 73 |
| 594 | 77– | 3786 | 3860 | 3933 | 4006 | 4079 | 4152 | 4225 | 4298 | 4371 | 4444 | 73 |
| 595 | 77– | 4517 | 4590 | 4663 | 4736 | 4809 | 4882 | 4955 | 5028 | 5100 | 5173 | 73 |
| 596 | 77– | 5246 | 5319 | 5392 | 5465 | 5538 | 5610 | 5683 | 5756 | 5829 | 5902 | 73 |
| 597 | 77– | 5974 | 6047 | 6120 | 6193 | 6265 | 6338 | 6411 | 6483 | 6556 | 6629 | 73 |
| 598 | 77– | 6701 | 6774 | 6846 | 6919 | 6992 | 7064 | 7137 | 7209 | 7282 | 7354 | 73 |
| 599 | 77– | 7427 | 7499 | 7572 | 7644 | 7717 | 7789 | 7862 | 7934 | 8006 | 8079 | 72 |
| 600 | 77– | 8151 | 8224 | 8296 | 8368 | 8441 | 8513 | 8585 | 8658 | 8730 | 8802 | 72 |
| 601 | 77– | 8874 | 8947 | 9019 | 9091 | 9163 | 9236 | 9308 | 9380 | 9452 | 9524 | 72 |
| 602 | 77– | 9596 | 9669 | 9741 | 9813 | 9885 | 9957 | .... | .... | .... | .... | 72 |
| 602 | 78– | .... | .... | .... | .... | .... | .... | 0029 | 0101 | 0173 | 0245 | 72 |
| 603 | 78– | 0317 | 0389 | 0461 | 0533 | 0605 | 0677 | 0749 | 0821 | 0893 | 0965 | 72 |
| 604 | 78– | 1037 | 1109 | 1181 | 1253 | 1324 | 1396 | 1468 | 1540 | 1612 | 1684 | 72 |
| 605 | 78– | 1755 | 1827 | 1899 | 1971 | 2042 | 2114 | 2186 | 2258 | 2329 | 2401 | 72 |
| 606 | 78– | 2473 | 2544 | 2616 | 2688 | 2759 | 2831 | 2902 | 2974 | 3046 | 3117 | 72 |
| 607 | 78– | 3189 | 3260 | 3332 | 3403 | 3475 | 3546 | 3618 | 3689 | 3761 | 3832 | 71 |
| 608 | 78– | 3904 | 3975 | 4046 | 4118 | 4189 | 4261 | 4332 | 4403 | 4475 | 4546 | 71 |
| 609 | 78– | 4617 | 4689 | 4760 | 4831 | 4902 | 4974 | 5045 | 5116 | 5187 | 5259 | 71 |
| 610 | 78– | 5330 | 5401 | 5472 | 5543 | 5615 | 5686 | 5757 | 5828 | 5899 | 5970 | 71 |
| 611 | 78– | 6041 | 6112 | 6183 | 6254 | 6325 | 6396 | 6467 | 6538 | 6609 | 6680 | 71 |
| 612 | 78– | 6751 | 6822 | 6893 | 6964 | 7035 | 7106 | 7177 | 7248 | 7319 | 7390 | 71 |
| 613 | 78– | 7460 | 7531 | 7602 | 7673 | 7744 | 7815 | 7885 | 7956 | 8027 | 8098 | 71 |
| 614 | 78– | 8168 | 8239 | 8310 | 8381 | 8451 | 8522 | 8593 | 8663 | 8734 | 8804 | 71 |
| 615 | 78– | 8875 | 8946 | 9016 | 9087 | 9157 | 9228 | 9299 | 9369 | 9440 | 9510 | 71 |
| 616 | 78– | 9581 | 9651 | 9722 | 9792 | 9863 | 9933 | .... | .... | .... | .... | 70 |
| 616 | 79– | .... | .... | .... | .... | .... | .... | 0004 | 0074 | 0144 | 0215 | 70 |
| 617 | 79– | 0285 | 0356 | 0426 | 0496 | 0567 | 0637 | 0707 | 0778 | 0848 | 0918 | 70 |
| 618 | 79– | 0988 | 1059 | 1129 | 1199 | 1269 | 1340 | 1410 | 1480 | 1550 | 1620 | 70 |
| 619 | 79– | 1691 | 1761 | 1831 | 1901 | 1971 | 2041 | 2111 | 2181 | 2252 | 2322 | 70 |
| 620 | 79– | 2392 | 2462 | 2532 | 2602 | 2672 | 2742 | 2812 | 2882 | 2952 | 3022 | 70 |
| 621 | 79– | 3092 | 3162 | 3231 | 3301 | 3371 | 3441 | 3511 | 3581 | 3651 | 3721 | 70 |
| 622 | 79– | 3790 | 3860 | 3930 | 4000 | 4070 | 4139 | 4209 | 4279 | 4349 | 4418 | 70 |
| 623 | 79– | 4488 | 4558 | 4627 | 4697 | 4767 | 4836 | 4906 | 4976 | 5045 | 5115 | 70 |
| 624 | 79– | 5185 | 5254 | 5324 | 5393 | 5463 | 5532 | 5602 | 5672 | 5741 | 5811 | 70 |
| 625 | 79– | 5880 | 5949 | 6019 | 6088 | 6158 | 6227 | 6297 | 6366 | 6436 | 6505 | 69 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

LOGARITHMS OF NUMBERS FROM 1 TO 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 626 | 79– | 6574 | 6644 | 6713 | 6782 | 6852 | 6921 | 6990 | 7060 | 7129 | 7198 | 69 |
| 627 | 79– | 7268 | 7337 | 7406 | 7475 | 7545 | 7614 | 7683 | 7752 | 7821 | 7890 | 69 |
| 628 | 79– | 7960 | 8029 | 8098 | 8167 | 8236 | 8305 | 8374 | 8443 | 8513 | 8582 | 69 |
| 629 | 79– | 8651 | 8720 | 8789 | 8858 | 8927 | 8996 | 9065 | 9134 | 9203 | 9272 | 69 |
| 630 | 79– | 9341 | 9409 | 9478 | 9547 | 9616 | 9685 | 9754 | 9823 | 9892 | 9961 | 69 |
| 631 | 80– | 0029 | 0098 | 0167 | 0236 | 0305 | 0373 | 0442 | 0511 | 0580 | 0648 | 69 |
| 632 | 80– | 0717 | 0786 | 0854 | 0923 | 0992 | 1061 | 1129 | 1198 | 1266 | 1335 | 69 |
| 633 | 80– | 1404 | 1472 | 1541 | 1609 | 1678 | 1747 | 1815 | 1884 | 1952 | 2021 | 69 |
| 634 | 80– | 2089 | 2158 | 2226 | 2295 | 2363 | 2432 | 2500 | 2568 | 2637 | 2705 | 69 |
| 635 | 80– | 2774 | 2842 | 2910 | 2979 | 3047 | 3116 | 3184 | 3252 | 3321 | 3389 | 68 |
| 636 | 80– | 3457 | 3525 | 3594 | 3662 | 3730 | 3798 | 3867 | 3935 | 4003 | 4071 | 68 |
| 637 | 80– | 4139 | 4208 | 4276 | 4344 | 4412 | 4480 | 4548 | 4616 | 4685 | 4753 | 68 |
| 638 | 80– | 4821 | 4889 | 4957 | 5025 | 5093 | 5161 | 5229 | 5297 | 5365 | 5433 | 68 |
| 639 | 80– | 5501 | 5569 | 5637 | 5705 | 5773 | 5841 | 5908 | 5976 | 6044 | 6112 | 68 |
| 640 | 80– | 6180 | 6248 | 6316 | 6384 | 6451 | 6519 | 6587 | 6655 | 6723 | 6790 | 68 |
| 641 | 80– | 6858 | 6926 | 6994 | 7061 | 7129 | 7197 | 7264 | 7332 | 7400 | 7467 | 68 |
| 642 | 80– | 7535 | 7603 | 7670 | 7738 | 7806 | 7873 | 7941 | 8008 | 8076 | 8143 | 68 |
| 643 | 80– | 8211 | 8279 | 8346 | 8414 | 8481 | 8549 | 8616 | 8684 | 8751 | 8818 | 67 |
| 644 | 80– | 8886 | 8953 | 9021 | 9088 | 9156 | 9223 | 9290 | 9358 | 9425 | 9492 | 67 |
| 645 | 80– | 9560 | 9627 | 9694 | 9762 | 9829 | 9896 | 9964 | .... | .... | .... | 67 |
| 645 | 81– | .... | .... | .... | .... | .... | .... | .... | 0031 | 0098 | 0165 | 67 |
| 646 | 81– | 0233 | 0300 | 0367 | 0434 | 0501 | 0569 | 0636 | 0703 | 0770 | 0837 | 67 |
| 647 | 81– | 0904 | 0971 | 1039 | 1106 | 1173 | 1240 | 1307 | 1374 | 1441 | 1508 | 67 |
| 648 | 81– | 1575 | 1642 | 1709 | 1776 | 1843 | 1910 | 1977 | 2044 | 2111 | 2178 | 67 |
| 649 | 81– | 2245 | 2312 | 2379 | 2445 | 2512 | 2579 | 2646 | 2713 | 2780 | 2847 | 67 |
| 650 | 81– | 2913 | 2980 | 3047 | 3114 | 3181 | 3247 | 3314 | 3381 | 3448 | 3514 | 67 |
| 651 | 81– | 3581 | 3648 | 3714 | 3781 | 3848 | 3914 | 3981 | 4048 | 4114 | 4181 | 67 |
| 652 | 81– | 4248 | 4314 | 4381 | 4447 | 4514 | 4581 | 4647 | 4714 | 4780 | 4847 | 67 |
| 653 | 81– | 4913 | 4980 | 5046 | 5113 | 5179 | 5246 | 5312 | 5378 | 5445 | 5511 | 66 |
| 654 | 81– | 5578 | 5644 | 5711 | 5777 | 5843 | 5910 | 5976 | 6042 | 6109 | 6175 | 66 |
| 655 | 81– | 6241 | 6308 | 6374 | 6440 | 6506 | 6573 | 6639 | 6705 | 6771 | 6838 | 66 |
| 656 | 81– | 6904 | 6970 | 7036 | 7102 | 7169 | 7235 | 7301 | 7367 | 7433 | 7499 | 66 |
| 657 | 81– | 7565 | 7631 | 7698 | 7764 | 7830 | 7896 | 7962 | 8028 | 8094 | 8160 | 66 |
| 658 | 81– | 8226 | 8292 | 8358 | 8424 | 8490 | 8556 | 8622 | 8638 | 8754 | 8820 | 66 |
| 659 | 81– | 8885 | 8951 | 9017 | 9083 | 9149 | 9215 | 9281 | 9346 | 9412 | 9478 | 66 |
| 660 | 81– | 9544 | 9610 | 9676 | 9741 | 9807 | 9873 | 9939 | .... | .... | .... | 66 |
| 660 | 82– | .... | .... | .... | .... | .... | .... | .... | 0004 | 0070 | 0136 | 66 |
| 661 | 82– | 0201 | 0267 | 0333 | 0399 | 0464 | 0530 | 0595 | 0661 | 0727 | 0792 | 66 |
| 662 | 82– | 0858 | 0924 | 0989 | 1055 | 1120 | 1186 | 1251 | 1317 | 1382 | 1448 | 66 |
| 663 | 82– | 1514 | 1579 | 1645 | 1710 | 1775 | 1841 | 1906 | 1972 | 2037 | 2103 | 65 |
| 664 | 82– | 2168 | 2233 | 2299 | 2364 | 2430 | 2495 | 2560 | 2626 | 2691 | 2756 | 65 |
| 665 | 82– | 2822 | 2887 | 2952 | 3018 | 3083 | 3148 | 3213 | 3279 | 3344 | 3409 | 65 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

LOGARITHMS OF NUMBERS FROM 1 TO 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 666 | 82– | 3474 | 3539 | 3605 | 3670 | 3735 | 3800 | 3865 | 3930 | 3996 | 4061 | 65 |
| 667 | 82– | 4126 | 4191 | 4256 | 4321 | 4386 | 4451 | 4516 | 4581 | 4646 | 4711 | 65 |
| 668 | 82– | 4776 | 4841 | 4906 | 4971 | 5036 | 5101 | 5166 | 5231 | 5296 | 5361 | 65 |
| 669 | 82– | 5426 | 5491 | 5556 | 5621 | 5686 | 5751 | 5815 | 5880 | 5945 | 6010 | 65 |
| 670 | 82– | 6075 | 6140 | 6204 | 6269 | 6334 | 6399 | 6464 | 6528 | 6593 | 6658 | 65 |
| 671 | 82– | 6723 | 6787 | 6852 | 6917 | 6981 | 7046 | 7111 | 7175 | 7240 | 7305 | 65 |
| 672 | 82– | 7369 | 7434 | 7499 | 7563 | 7628 | 7692 | 7757 | 7821 | 7886 | 7951 | 65 |
| 673 | 82– | 8015 | 8080 | 8144 | 8209 | 8273 | 8338 | 8402 | 8467 | 8531 | 8595 | 64 |
| 674 | 82– | 8660 | 8724 | 8789 | 8853 | 8918 | 8982 | 9046 | 9111 | 9175 | 9239 | 64 |
| 675 | 82– | 9304 | 9368 | 9432 | 9497 | 9561 | 9625 | 9690 | 9754 | 9818 | 9882 | 64 |
| 676 | 82– | 9947 | .... | .... | .... | .... | .... | .... | .... | .... | .... | 64 |
| 676 | 83– | .... | 0011 | 0075 | 0139 | 0204 | 0268 | 0332 | 0396 | 0460 | 0525 | 64 |
| 677 | 83– | 0589 | 0653 | 0717 | 0781 | 0845 | 0909 | 0973 | 1037 | 1102 | 1166 | 64 |
| 678 | 83– | 1230 | 1294 | 1358 | 1422 | 1486 | 1550 | 1614 | 1678 | 1742 | 1806 | 64 |
| 679 | 83– | 1870 | 1934 | 1998 | 2062 | 2126 | 2189 | 2253 | 2317 | 2381 | 2445 | 64 |
| 680 | 83– | 2509 | 2573 | 2637 | 2700 | 2764 | 2828 | 2892 | 2956 | 3020 | 3083 | 64 |
| 681 | 83– | 3147 | 3211 | 3275 | 3338 | 3402 | 3466 | 3530 | 3593 | 3657 | 3721 | 64 |
| 682 | 83– | 3784 | 3848 | 3912 | 3975 | 4039 | 4103 | 4166 | 4230 | 4294 | 4357 | 64 |
| 683 | 83– | 4421 | 4484 | 4548 | 4611 | 4675 | 4739 | 4802 | 4866 | 4929 | 4993 | 64 |
| 684 | 83– | 5056 | 5120 | 5183 | 5247 | 5310 | 5373 | 5437 | 5500 | 5564 | 5627 | 63 |
| 685 | 83– | 5691 | 5754 | 5817 | 5881 | 5944 | 6007 | 6071 | 6134 | 6197 | 6261 | 63 |
| 686 | 83– | 6324 | 6387 | 6451 | 6514 | 6577 | 6641 | 6704 | 6767 | 6830 | 6894 | 63 |
| 687 | 83– | 6957 | 7020 | 7083 | 7146 | 7210 | 7273 | 7336 | 7399 | 7462 | 7525 | 63 |
| 688 | 83– | 7588 | 7652 | 7715 | 7778 | 7841 | 7904 | 7967 | 8030 | 8093 | 8156 | 63 |
| 689 | 83– | 8219 | 8282 | 8345 | 8408 | 8471 | 8534 | 8597 | 8660 | 8723 | 8786 | 63 |
| 690 | 83– | 8849 | 8912 | 8975 | 9038 | 9101 | 9164 | 9227 | 9289 | 9352 | 9415 | 63 |
| 691 | 83– | 9478 | 9541 | 9604 | 9667 | 9729 | 9792 | 9855 | 9918 | 9981 | .... | 63 |
| 691 | 84– | .... | .... | .... | .... | .... | .... | .... | .... | .... | 0043 | 63 |
| 692 | 84– | 0106 | 0169 | 0232 | 0294 | 0357 | 0420 | 0482 | 0545 | 0608 | 0671 | 63 |
| 693 | 84– | 0733 | 0796 | 0859 | 0921 | 0984 | 1046 | 1109 | 1172 | 1234 | 1297 | 63 |
| 694 | 84– | 1359 | 1422 | 1485 | 1547 | 1610 | 1672 | 1735 | 1797 | 1860 | 1922 | 63 |
| 695 | 84– | 1985 | 2047 | 2110 | 2172 | 2235 | 2297 | 2360 | 2422 | 2484 | 2547 | 62 |
| 696 | 84– | 2609 | 2672 | 2734 | 2796 | 2859 | 2921 | 2983 | 3046 | 3108 | 3170 | 62 |
| 697 | 84– | 3233 | 3295 | 3357 | 3420 | 3482 | 3544 | 3606 | 3669 | 3731 | 3793 | 62 |
| 698 | 84– | 3855 | 3918 | 3980 | 4042 | 4104 | 4166 | 4229 | 4291 | 4353 | 4415 | 62 |
| 699 | 84– | 4477 | 4539 | 4601 | 4664 | 4726 | 4788 | 4850 | 4912 | 4974 | 5036 | 62 |
| 700 | 84– | 5098 | 5160 | 5222 | 5284 | 5346 | 5408 | 5470 | 5532 | 5594 | 5656 | 62 |
| 701 | 84– | 5718 | 5780 | 5842 | 5904 | 5966 | 6028 | 6090 | 6151 | 6213 | 6275 | 62 |
| 702 | 84– | 6337 | 6399 | 6461 | 6523 | 6585 | 6646 | 6708 | 6770 | 6832 | 6894 | 62 |
| 703 | 84– | 6955 | 7017 | 7079 | 7141 | 7202 | 7264 | 7326 | 7388 | 7449 | 7511 | 62 |
| 704 | 84– | 7573 | 7634 | 7696 | 7758 | 7819 | 7881 | 7943 | 8004 | 8066 | 8128 | 62 |
| 705 | 84– | 8189 | 8251 | 8312 | 8374 | 8435 | 8497 | 8559 | 8620 | 8682 | 8743 | 62 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

LOGARITHMS OF NUMBERS FROM 1 TO 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 706 | 84– | 8805 | 8866 | 8928 | 8989 | 9051 | 9112 | 9174 | 9235 | 9297 | 9358 | 61 |
| 707 | 84– | 9419 | 9481 | 9542 | 9604 | 9665 | 9726 | 9788 | 9849 | 9911 | 9972 | 61 |
| 708 | 85– | 0033 | 0095 | 0156 | 0217 | 0279 | 0340 | 0401 | 0462 | 0524 | 0585 | 61 |
| 709 | 85– | 0646 | 0707 | 0769 | 0830 | 0891 | 0952 | 1014 | 1075 | 1136 | 1197 | 61 |
| 710 | 85– | 1258 | 1320 | 1381 | 1442 | 1503 | 1564 | 1625 | 1686 | 1747 | 1809 | 61 |
| 711 | 85– | 1870 | 1931 | 1992 | 2053 | 2114 | 2175 | 2236 | 2297 | 2358 | 2419 | 61 |
| 712 | 85– | 2480 | 2541 | 2602 | 2663 | 2724 | 2785 | 2846 | 2907 | 2968 | 3029 | 61 |
| 713 | 85– | 3090 | 3150 | 3211 | 3272 | 3333 | 3394 | 3455 | 3516 | 3577 | 3637 | 61 |
| 714 | 85– | 3698 | 3759 | 3820 | 3881 | 3941 | 4002 | 4063 | 4124 | 4185 | 4245 | 61 |
| 715 | 85– | 4306 | 4367 | 4428 | 4488 | 4549 | 4610 | 4670 | 4731 | 4792 | 4852 | 61 |
| 716 | 85– | 4913 | 4974 | 5034 | 5095 | 5156 | 5216 | 5277 | 5337 | 5398 | 5459 | 61 |
| 717 | 85– | 5519 | 5580 | 5640 | 5701 | 5761 | 5822 | 5882 | 5943 | 6003 | 6064 | 61 |
| 718 | 85– | 6124 | 6185 | 6245 | 6306 | 6366 | 6427 | 6487 | 6548 | 6608 | 6668 | 60 |
| 719 | 85– | 6729 | 6789 | 6850 | 6910 | 6970 | 7031 | 7091 | 7152 | 7212 | 7272 | 60 |
| 720 | 85– | 7332 | 7393 | 7453 | 7513 | 7574 | 7634 | 7694 | 7755 | 7815 | 7875 | 60 |
| 721 | 85– | 7935 | 7995 | 8056 | 8116 | 8176 | 8236 | 8297 | 8357 | 8417 | 8477 | 60 |
| 722 | 85– | 8537 | 8597 | 8657 | 8718 | 8778 | 8838 | 8898 | 8958 | 9018 | 9078 | 60 |
| 723 | 85– | 9138 | 9198 | 9258 | 9318 | 9379 | 9439 | 9499 | 9559 | 9619 | 9679 | 60 |
| 724 | 85– | 9739 | 9799 | 9859 | 9918 | 9978 | .... | .... | .... | .... | .... | 60 |
| 724 | 86– | .... | .... | .... | .... | .... | 0038 | 0098 | 0158 | 0218 | 0278 | 60 |
| 725 | 86– | 0338 | 0398 | 0458 | 0518 | 0578 | 0637 | 0697 | 0757 | 0817 | 0877 | 60 |
| 726 | 86– | 0937 | 0996 | 1056 | 1116 | 1176 | 1236 | 1295 | 1355 | 1415 | 1475 | 60 |
| 727 | 86– | 1534 | 1594 | 1654 | 1714 | 1773 | 1833 | 1893 | 1952 | 2012 | 2072 | 60 |
| 728 | 86– | 2131 | 2191 | 2251 | 2310 | 2370 | 2430 | 2489 | 2549 | 2608 | 2668 | 60 |
| 729 | 86– | 2728 | 2787 | 2847 | 2906 | 2966 | 3025 | 3085 | 3144 | 3204 | 3263 | 60 |
| 730 | 86– | 3323 | 3382 | 3442 | 3501 | 3561 | 3620 | 3680 | 3739 | 3799 | 3858 | 59 |
| 731 | 86– | 3917 | 3977 | 4036 | 4096 | 4155 | 4214 | 4274 | 4333 | 4392 | 4452 | 59 |
| 732 | 86– | 4511 | 4570 | 4630 | 4689 | 4748 | 4808 | 4867 | 4926 | 4985 | 5045 | 59 |
| 733 | 86– | 5104 | 5163 | 5222 | 5282 | 5341 | 5400 | 5459 | 5519 | 5578 | 5637 | 59 |
| 734 | 86– | 5696 | 5755 | 5814 | 5874 | 5933 | 5992 | 6051 | 6110 | 6169 | 6228 | 59 |
| 735 | 86– | 6287 | 6346 | 6405 | 6465 | 6524 | 6583 | 6642 | 6701 | 6760 | 6819 | 59 |
| 736 | 86– | 6878 | 6937 | 6996 | 7055 | 7114 | 7173 | 7232 | 7291 | 7350 | 7409 | 59 |
| 737 | 86– | 7467 | 7526 | 7585 | 7644 | 7703 | 7762 | 7821 | 7880 | 7939 | 7998 | 59 |
| 738 | 86– | 8056 | 8115 | 8174 | 8233 | 8292 | 8350 | 8409 | 8468 | 8527 | 8586 | 59 |
| 739 | 86– | 8644 | 8703 | 8762 | 8821 | 8870 | 8938 | 8997 | 9056 | 9114 | 9173 | 59 |
| 740 | 86– | 9232 | 9290 | 9349 | 9408 | 9466 | 9525 | 9584 | 9642 | 9701 | 9760 | 59 |
| 741 | 86– | 9818 | 9877 | 9935 | 9994 | .... | .... | .... | .... | .... | .... | 59 |
| 741 | 87– | .... | .... | .... | .... | 0053 | 0111 | 0170 | 0228 | 0287 | 0345 | 59 |
| 742 | 87– | 0404 | 0462 | 0521 | 0579 | 0638 | 0696 | 0755 | 0813 | 0872 | 0930 | 58 |
| 743 | 87– | 0989 | 1047 | 1106 | 1164 | 1223 | 1281 | 1339 | 1398 | 1456 | 1515 | 58 |
| 744 | 87– | 1573 | 1631 | 1690 | 1748 | 1806 | 1865 | 1923 | 1981 | 2040 | 2098 | 58 |
| 745 | 87– | 2156 | 2215 | 2273 | 2331 | 2389 | 2448 | 2506 | 2564 | 2622 | 2681 | 58 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

Logarithms of Numbers from 1 to 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 746 | 87– | 2739 | 2797 | 2855 | 2913 | 2972 | 3030 | 3088 | 3146 | 3204 | 3262 | 58 |
| 747 | 87– | 3321 | 3379 | 3437 | 3495 | 3553 | 3611 | 3669 | 3727 | 3785 | 3844 | 58 |
| 748 | 87– | 3902 | 3960 | 4018 | 4076 | 4134 | 4192 | 4250 | 4308 | 4366 | 4424 | 58 |
| 749 | 87– | 4482 | 4540 | 4598 | 4656 | 4714 | 4772 | 4830 | 4888 | 4945 | 5003 | 58 |
| 750 | 87– | 5061 | 5119 | 5177 | 5235 | 5293 | 5351 | 5409 | 5466 | 5524 | 5582 | 58 |
| 751 | 87– | 5640 | 5698 | 5756 | 5813 | 5871 | 5929 | 5987 | 6045 | 6102 | 6160 | 58 |
| 752 | 87– | 6218 | 6276 | 6333 | 6391 | 6449 | 6507 | 6564 | 6622 | 6680 | 6737 | 58 |
| 753 | 87– | 6795 | 6853 | 6910 | 6968 | 7026 | 7083 | 7141 | 7199 | 7256 | 7314 | 58 |
| 754 | 87– | 7371 | 7429 | 7487 | 7544 | 7602 | 7659 | 7717 | 7774 | 7832 | 7889 | 58 |
| 755 | 87– | 7947 | 8004 | 8062 | 8119 | 8177 | 8234 | 8292 | 8349 | 8407 | 8464 | 57 |
| 756 | 87– | 8522 | 8579 | 8637 | 8694 | 8752 | 8809 | 8866 | 8924 | 8981 | 9039 | 57 |
| 757 | 87– | 9096 | 9153 | 9211 | 9268 | 9325 | 9383 | 9440 | 9497 | 9555 | 9612 | 57 |
| 758 | 87– | 9669 | 9726 | 9784 | 9841 | 9898 | 9956 | .... | .... | .... | .... | 57 |
| 758 | 88– | .... | .... | .... | .... | .... | .... | 0013 | 0070 | 0127 | 0185 | 57 |
| 759 | 88– | 0242 | 0299 | 0356 | 0413 | 0471 | 0528 | 0585 | 0642 | 0699 | 0756 | 57 |
| 760 | 88– | 0814 | 0871 | 0928 | 0985 | 1042 | 1099 | 1156 | 1213 | 1271 | 1328 | 57 |
| 761 | 88– | 1385 | 1442 | 1499 | 1556 | 1613 | 1670 | 1727 | 1784 | 1841 | 1898 | 57 |
| 762 | 88– | 1955 | 2012 | 2069 | 2126 | 2183 | 2240 | 2297 | 2354 | 2411 | 2468 | 57 |
| 763 | 88– | 2525 | 2581 | 2638 | 2695 | 2752 | 2809 | 2866 | 2923 | 2980 | 3037 | 57 |
| 764 | 88– | 3093 | 3150 | 3207 | 3264 | 3321 | 3377 | 3434 | 3491 | 3548 | 3605 | 57 |
| 765 | 88– | 3661 | 3718 | 3775 | 3832 | 3888 | 3945 | 4002 | 4059 | 4115 | 4172 | 57 |
| 766 | 88– | 4229 | 4285 | 4342 | 4399 | 4455 | 4512 | 4569 | 4625 | 4682 | 4739 | 57 |
| 767 | 88– | 4795 | 4852 | 4909 | 4965 | 5022 | 5078 | 5135 | 5192 | 5248 | 5305 | 57 |
| 768 | 88– | 5361 | 5418 | 5474 | 5531 | 5587 | 5644 | 5700 | 5757 | 5813 | 5870 | 57 |
| 769 | 88– | 5926 | 5983 | 6039 | 6096 | 6152 | 6209 | 6265 | 6321 | 6378 | 6434 | 56 |
| 770 | 88– | 6491 | 6547 | 6604 | 6660 | 6716 | 6773 | 6829 | 6885 | 6942 | 6998 | 56 |
| 771 | 88– | 7054 | 7111 | 7167 | 7223 | 7280 | 7336 | 7392 | 7449 | 7505 | 7561 | 56 |
| 772 | 88– | 7617 | 7674 | 7730 | 7786 | 7842 | 7898 | 7955 | 8011 | 8067 | 8123 | 56 |
| 773 | 88– | 8179 | 8236 | 8292 | 8348 | 8404 | 8460 | 8516 | 8573 | 8629 | 8685 | 56 |
| 774 | 88– | 8741 | 8797 | 8853 | 8909 | 8965 | 9021 | 9077 | 9134 | 9190 | 9246 | 56 |
| 775 | 88– | 9302 | 9358 | 9414 | 9470 | 9526 | 9582 | 9638 | 9694 | 9750 | 9806 | 56 |
| 776 | 88– | 9862 | 9918 | 9974 | .... | .... | .... | .... | .... | .... | .... | 56 |
| 776 | 89– | .... | .... | .... | 0030 | 0086 | 0141 | 0197 | 0253 | 0309 | 0365 | 56 |
| 777 | 89– | 0421 | 0477 | 0533 | 0589 | 0645 | 0700 | 0756 | 0812 | 0868 | 0924 | 56 |
| 778 | 89– | 0980 | 1035 | 1091 | 1147 | 1203 | 1259 | 1314 | 1370 | 1426 | 1482 | 56 |
| 779 | 89– | 1537 | 1593 | 1649 | 1705 | 1760 | 1816 | 1872 | 1928 | 1983 | 2039 | 56 |
| 780 | 89– | 2095 | 2150 | 2206 | 2262 | 2317 | 2373 | 2429 | 2484 | 2540 | 2595 | 56 |
| 781 | 89– | 2651 | 2707 | 2762 | 2818 | 2873 | 2929 | 2985 | 3040 | 3096 | 3151 | 56 |
| 782 | 89– | 3207 | 3262 | 3318 | 3373 | 3429 | 3484 | 3540 | 3595 | 3651 | 3706 | 56 |
| 783 | 89– | 3762 | 3817 | 3873 | 3928 | 3984 | 4039 | 4094 | 4150 | 4205 | 4261 | 55 |
| 784 | 89– | 4316 | 4371 | 4427 | 4482 | 4538 | 4593 | 4648 | 4704 | 4759 | 4814 | 55 |
| 785 | 89– | 4870 | 4925 | 4980 | 5036 | 5091 | 5146 | 5201 | 5257 | 5312 | 5367 | 55 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

Logarithms of Numbers from 1 to 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 786 | 89– | 5423 | 5478 | 5533 | 5588 | 5644 | 5699 | 5754 | 5809 | 5864 | 5920 | 55 |
| 787 | 89– | 5975 | 6030 | 6085 | 6140 | 6195 | 6251 | 6306 | 6361 | 6416 | 6471 | 55 |
| 788 | 89– | 6526 | 6581 | 6636 | 6692 | 6747 | 6802 | 6857 | 6912 | 6967 | 7022 | 55 |
| 789 | 89– | 7077 | 7132 | 7187 | 7242 | 7297 | 7352 | 7407 | 7462 | 7517 | 7572 | 55 |
| 790 | 89– | 7627 | 7682 | 7737 | 7792 | 7847 | 7902 | 7957 | 8012 | 8067 | 8122 | 55 |
| 791 | 89– | 8176 | 8231 | 8286 | 8341 | 8396 | 8451 | 8506 | 8561 | 8615 | 8670 | 55 |
| 792 | 89– | 8725 | 8780 | 8835 | 8890 | 8944 | 8999 | 9054 | 9109 | 9164 | 9218 | 55 |
| 793 | 89– | 9273 | 9328 | 9383 | 9437 | 9492 | 9547 | 9602 | 9656 | 9711 | 9766 | 55 |
| 794 | 89– | 9821 | 9875 | 9930 | 9985 | .... | .... | .... | .... | .... | .... | 55 |
| 794 | 90– | .... | .... | .... | .... | 0039 | 0094 | 0149 | 0203 | 0258 | 0312 | 55 |
| 795 | 90– | 0367 | 0422 | 0476 | 0531 | 0586 | 0640 | 0695 | 0749 | 0804 | 0859 | 55 |
| 796 | 90– | 0913 | 0968 | 1022 | 1077 | 1131 | 1186 | 1240 | 1295 | 1349 | 1404 | 55 |
| 797 | 90– | 1458 | 1513 | 1567 | 1622 | 1676 | 1731 | 1785 | 1840 | 1894 | 1948 | 54 |
| 798 | 90– | 2003 | 2057 | 2112 | 2166 | 2221 | 2275 | 2329 | 2384 | 2438 | 2492 | 54 |
| 799 | 90– | 2547 | 2601 | 2655 | 2710 | 2764 | 2818 | 2873 | 2927 | 2981 | 3036 | 54 |
| 800 | 90– | 3090 | 3144 | 3199 | 3253 | 3307 | 3361 | 3416 | 3470 | 3524 | 3578 | 54 |
| 801 | 90– | 3633 | 3687 | 3741 | 3795 | 3849 | 3904 | 3958 | 4012 | 4066 | 4120 | 54 |
| 802 | 90– | 4174 | 4229 | 4283 | 4337 | 4391 | 4445 | 4499 | 4553 | 4607 | 4661 | 54 |
| 803 | 90– | 4716 | 4770 | 4824 | 4878 | 4932 | 4986 | 5040 | 5094 | 5148 | 5202 | 54 |
| 804 | 90– | 5256 | 5310 | 5364 | 5418 | 5472 | 5526 | 5580 | 5634 | 5688 | 5742 | 54 |
| 805 | 90– | 5796 | 5850 | 5904 | 5958 | 6012 | 6066 | 6119 | 6173 | 6227 | 6281 | 54 |
| 806 | 90– | 6335 | 6389 | 6443 | 6497 | 6551 | 6604 | 6658 | 6712 | 6766 | 6820 | 54 |
| 807 | 90– | 6874 | 6927 | 6981 | 7035 | 7089 | 7143 | 7196 | 7250 | 7304 | 7358 | 54 |
| 808 | 90– | 7411 | 7465 | 7519 | 7573 | 7626 | 7680 | 7734 | 7787 | 7841 | 7895 | 54 |
| 809 | 90– | 7949 | 8002 | 8056 | 8110 | 8163 | 8217 | 8270 | 8324 | 8378 | 8431 | 54 |
| 810 | 90– | 8485 | 8539 | 8592 | 8646 | 8699 | 8753 | 8807 | 8860 | 8914 | 8967 | 54 |
| 811 | 90– | 9021 | 9074 | 9128 | 9181 | 9235 | 9289 | 9342 | 9396 | 9449 | 9503 | 54 |
| 812 | 90– | 9556 | 9610 | 9663 | 9716 | 9770 | 9823 | 9877 | 9930 | 9984 | .... | 54 |
| 812 | 91– | .... | .... | .... | .... | .... | .... | .... | .... | .... | 0037 | 53 |
| 813 | 91– | 0091 | 0144 | 0197 | 0251 | 0304 | 0358 | 0411 | 0464 | 0518 | 0571 | 53 |
| 814 | 91– | 0624 | 0678 | 0731 | 0784 | 0838 | 0891 | 0944 | 0998 | 1051 | 1104 | 53 |
| 815 | 91– | 1158 | 1211 | 1264 | 1317 | 1371 | 1424 | 1477 | 1530 | 1584 | 1637 | 53 |
| 816 | 91– | 1690 | 1743 | 1797 | 1850 | 1903 | 1956 | 2009 | 2063 | 2116 | 2169 | 53 |
| 817 | 91– | 2222 | 2275 | 2328 | 2381 | 2435 | 2488 | 2541 | 2594 | 2647 | 2700 | 53 |
| 818 | 91– | 2753 | 2806 | 2859 | 2913 | 2966 | 3019 | 3072 | 3125 | 3178 | 3231 | 53 |
| 819 | 91– | 3284 | 3337 | 3390 | 3443 | 3496 | 3549 | 3602 | 3655 | 3708 | 3761 | 53 |
| 820 | 91– | 3814 | 3867 | 3920 | 3973 | 4026 | 4079 | 4132 | 4184 | 4237 | 4290 | 53 |
| 821 | 91– | 4343 | 4396 | 4449 | 4502 | 4555 | 4608 | 4660 | 4713 | 4766 | 4819 | 53 |
| 822 | 91– | 4872 | 4925 | 4977 | 5030 | 5083 | 5136 | 5189 | 5241 | 5294 | 5347 | 53 |
| 823 | 91– | 5400 | 5453 | 5505 | 5558 | 5611 | 5664 | 5716 | 5769 | 5822 | 5875 | 53 |
| 824 | 91– | 5927 | 5980 | 6033 | 6085 | 6138 | 6191 | 6243 | 6296 | 6349 | 6401 | 53 |
| 825 | 91– | 6454 | 6507 | 6559 | 6612 | 6664 | 6717 | 6770 | 6822 | 6875 | 6927 | 53 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

LOGARITHMS OF NUMBERS FROM 1 TO 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 826 | 91– | 6980 | 7033 | 7085 | 7138 | 7190 | 7243 | 7295 | 7348 | 7400 | 7453 | 53 |
| 827 | 91– | 7506 | 7558 | 7611 | 7663 | 7716 | 7768 | 7820 | 7873 | 7925 | 7978 | 52 |
| 828 | 91– | 8030 | 8083 | 8135 | 8188 | 8240 | 8293 | 8345 | 8397 | 8450 | 8502 | 52 |
| 829 | 91– | 8555 | 8607 | 8659 | 8712 | 8764 | 8816 | 8869 | 8921 | 8973 | 9026 | 52 |
| 830 | 91– | 9078 | 9130 | 9183 | 9235 | 9287 | 9340 | 9392 | 9444 | 9496 | 9549 | 52 |
| 831 | 91– | 9601 | 9653 | 9706 | 9758 | 9810 | 9862 | 9914 | 9967 | .... | .... | 52 |
| 831 | 92– | .... | .... | .... | .... | .... | .... | .... | .... | 0019 | 0071 | 52 |
| 832 | 92– | 0123 | 0176 | 0228 | 0280 | 0332 | 0384 | 0436 | 0489 | 0541 | 0593 | 52 |
| 833 | 92– | 0645 | 0697 | 0749 | 0801 | 0853 | 0906 | 0958 | 1010 | 1062 | 1114 | 52 |
| 834 | 92– | 1166 | 1218 | 1270 | 1322 | 1374 | 1426 | 1478 | 1530 | 1582 | 1634 | 52 |
| 835 | 92– | 1686 | 1738 | 1790 | 1842 | 1894 | 1946 | 1998 | 2050 | 2102 | 2154 | 52 |
| 836 | 92– | 2206 | 2258 | 2310 | 2362 | 2414 | 2466 | 2518 | 2570 | 2622 | 2674 | 52 |
| 837 | 92– | 2725 | 2777 | 2829 | 2881 | 2933 | 2985 | 3037 | 3089 | 3140 | 3192 | 52 |
| 838 | 92– | 3244 | 3296 | 3348 | 3399 | 3451 | 3503 | 3555 | 3607 | 3658 | 3710 | 52 |
| 839 | 92– | 3762 | 3814 | 3865 | 3917 | 3969 | 4021 | 4072 | 4124 | 4176 | 4228 | 52 |
| 840 | 92– | 4279 | 4331 | 4383 | 4434 | 4486 | 4538 | 4589 | 4641 | 4693 | 4744 | 52 |
| 841 | 92– | 4796 | 4848 | 4899 | 4951 | 5003 | 5054 | 5106 | 5157 | 5209 | 5261 | 52 |
| 842 | 92– | 5312 | 5364 | 5415 | 5467 | 5518 | 5570 | 5621 | 5673 | 5725 | 5776 | 52 |
| 843 | 92– | 5828 | 5879 | 5931 | 5982 | 6034 | 6085 | 6137 | 6188 | 6240 | 6291 | 51 |
| 844 | 92– | 6342 | 6394 | 6445 | 6497 | 6548 | 6600 | 6651 | 6702 | 6754 | 6805 | 51 |
| 845 | 92– | 6857 | 6908 | 6959 | 7011 | 7062 | 7114 | 7165 | 7216 | 7268 | 7319 | 51 |
| 846 | 92– | 7370 | 7422 | 7473 | 7524 | 7576 | 7627 | 7678 | 7730 | 7781 | 7832 | 51 |
| 847 | 92– | 7883 | 7935 | 7986 | 8037 | 8088 | 8140 | 8191 | 8242 | 8293 | 8345 | 51 |
| 848 | 92– | 8396 | 8447 | 8498 | 8549 | 8601 | 8652 | 8703 | 8754 | 8805 | 8857 | 51 |
| 849 | 92– | 8908 | 8959 | 9010 | 9061 | 9112 | 9163 | 9215 | 9266 | 9317 | 9368 | 51 |
| 850 | 92– | 9419 | 9470 | 9521 | 9572 | 9623 | 9674 | 9725 | 9776 | 9827 | 9879 | 51 |
| 851 | 92– | 9930 | 9981 | .... | .... | .... | .... | .... | .... | .... | .... | 51 |
| 851 | 93– | .... | .... | 0032 | 0083 | 0134 | 0185 | 0236 | 0287 | 0338 | 0389 | 51 |
| 852 | 93– | 0440 | 0491 | 0542 | 0592 | 0643 | 0694 | 0745 | 0796 | 0847 | 0898 | 51 |
| 853 | 93– | 0949 | 1000 | 1051 | 1102 | 1153 | 1203 | 1254 | 1305 | 1356 | 1407 | 51 |
| 854 | 93– | 1458 | 1509 | 1560 | 1610 | 1661 | 1712 | 1763 | 1814 | 1865 | 1915 | 51 |
| 855 | 93– | 1966 | 2017 | 2068 | 2118 | 2169 | 2220 | 2271 | 2322 | 2372 | 2423 | 51 |
| 856 | 93– | 2474 | 2524 | 2575 | 2626 | 2677 | 2727 | 2778 | 2829 | 2879 | 2930 | 51 |
| 857 | 93– | 2981 | 3031 | 3082 | 3133 | 3183 | 3234 | 3285 | 3335 | 3386 | 3437 | 51 |
| 858 | 93– | 3487 | 3538 | 3589 | 3639 | 3690 | 3740 | 3791 | 3841 | 3892 | 3943 | 51 |
| 859 | 93– | 3993 | 4044 | 4094 | 4145 | 4195 | 4246 | 4296 | 4347 | 4397 | 4448 | 51 |
| 860 | 93– | 4498 | 4549 | 4599 | 4650 | 4700 | 4751 | 4801 | 4852 | 4902 | 4953 | 50 |
| 861 | 93– | 5003 | 5054 | 5104 | 5154 | 5205 | 5255 | 5306 | 5356 | 5406 | 5457 | 50 |
| 862 | 93– | 5507 | 5558 | 5608 | 5658 | 5709 | 5759 | 5809 | 5860 | 5910 | 5960 | 50 |
| 863 | 93– | 6011 | 6061 | 6111 | 6162 | 6212 | 6262 | 6313 | 6363 | 6413 | 6463 | 50 |
| 864 | 93– | 6514 | 6564 | 6614 | 6665 | 6715 | 6765 | 6815 | 6865 | 6916 | 6966 | 50 |
| 865 | 93– | 7016 | 7066 | 7117 | 7167 | 7217 | 7267 | 7317 | 7367 | 7418 | 7468 | 50 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

LOGARITHMS OF NUMBERS FROM 1 TO 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 866 | 93– | 7518 | 7568 | 7618 | 7668 | 7718 | 7769 | 7819 | 7869 | 7919 | 7969 | 50 |
| 867 | 93– | 8019 | 8069 | 8119 | 8169 | 8219 | 8269 | 8319 | 8370 | 8420 | 8470 | 50 |
| 868 | 93– | 8520 | 8570 | 8620 | 8670 | 8720 | 8770 | 8820 | 8870 | 8920 | 8970 | 50 |
| 869 | 93– | 9020 | 9070 | 9120 | 9170 | 9220 | 9270 | 9320 | 9369 | 9419 | 9469 | 50 |
| 870 | 93– | 9519 | 9569 | 9619 | 9669 | 9719 | 9769 | 9819 | 9869 | 9918 | 9968 | 50 |
| 871 | 94– | 0018 | 0068 | 0118 | 0168 | 0218 | 0267 | 0317 | 0367 | 0417 | 0467 | 50 |
| 872 | 94– | 0516 | 0566 | 0616 | 0666 | 0716 | 0765 | 0815 | 0865 | 0915 | 0964 | 50 |
| 873 | 94– | 1014 | 1064 | 1114 | 1163 | 1213 | 1263 | 1313 | 1362 | 1412 | 1462 | 50 |
| 874 | 94– | 1511 | 1561 | 1611 | 1660 | 1710 | 1760 | 1809 | 1859 | 1909 | 1958 | 50 |
| 875 | 94– | 2008 | 2058 | 2107 | 2157 | 2207 | 2256 | 2306 | 2355 | 2405 | 2455 | 50 |
| 876 | 94– | 2504 | 2554 | 2603 | 2653 | 2702 | 2752 | 2801 | 2851 | 2901 | 2950 | 50 |
| 877 | 94– | 3000 | 3049 | 3099 | 3148 | 3198 | 3247 | 3297 | 3346 | 3396 | 3445 | 49 |
| 878 | 94– | 3495 | 3544 | 3593 | 3643 | 3692 | 3742 | 3791 | 3841 | 3890 | 3939 | 49 |
| 879 | 94– | 3989 | 4038 | 4088 | 4137 | 4186 | 4236 | 4285 | 4335 | 4384 | 4433 | 49 |
| 880 | 94– | 4483 | 4532 | 4581 | 4631 | 4680 | 4729 | 4779 | 4828 | 4877 | 4927 | 49 |
| 881 | 94– | 4976 | 5025 | 5074 | 5124 | 5173 | 5222 | 5272 | 5321 | 5370 | 5419 | 49 |
| 882 | 94– | 5469 | 5518 | 5567 | 5616 | 5665 | 5715 | 5764 | 5813 | 5862 | 5912 | 49 |
| 883 | 94– | 5961 | 6010 | 6059 | 6108 | 6157 | 6207 | 6256 | 6305 | 6354 | 6403 | 49 |
| 884 | 94– | 6452 | 6501 | 6551 | 6600 | 6649 | 6698 | 6747 | 6796 | 6845 | 6894 | 49 |
| 885 | 94– | 6943 | 6992 | 7041 | 7090 | 7140 | 7189 | 7238 | 7287 | 7336 | 7385 | 49 |
| 886 | 94– | 7434 | 7483 | 7532 | 7581 | 7630 | 7679 | 7728 | 7777 | 7826 | 7875 | 49 |
| 887 | 94– | 7924 | 7973 | 8022 | 8070 | 8119 | 8168 | 8217 | 8266 | 8315 | 8364 | 49 |
| 888 | 94– | 8413 | 8462 | 8511 | 8560 | 8609 | 8657 | 8706 | 8755 | 8804 | 8853 | 49 |
| 889 | 94– | 8902 | 8951 | 8999 | 9048 | 9097 | 9146 | 9195 | 9244 | 9292 | 9341 | 49 |
| 890 | 94– | 9390 | 9439 | 9488 | 9536 | 9585 | 9634 | 9683 | 9731 | 9780 | 9829 | 49 |
| 891 | 94– | 9878 | 9926 | 9975 | .... | .... | .... | .... | .... | .... | .... | 49 |
| 891 | 95– | .... | .... | .... | 0024 | 0073 | 0121 | 0170 | 0219 | 0267 | 0316 | 49 |
| 892 | 95– | 0365 | 0414 | 0462 | 0511 | 0560 | 0608 | 0657 | 0706 | 0754 | 0803 | 49 |
| 893 | 95– | 0851 | 0900 | 0949 | 0997 | 1046 | 1095 | 1143 | 1192 | 1240 | 1289 | 49 |
| 894 | 95– | 1338 | 1386 | 1435 | 1483 | 1532 | 1580 | 1629 | 1677 | 1726 | 1775 | 49 |
| 895 | 95– | 1823 | 1872 | 1920 | 1969 | 2017 | 2066 | 2114 | 2163 | 2211 | 2260 | 48 |
| 896 | 95– | 2308 | 2356 | 2405 | 2453 | 2502 | 2550 | 2599 | 2647 | 2696 | 2744 | 48 |
| 897 | 95– | 2792 | 2841 | 2889 | 2938 | 2986 | 3034 | 3083 | 3131 | 3180 | 3228 | 48 |
| 898 | 95– | 3276 | 3325 | 3373 | 3421 | 3470 | 3518 | 3566 | 3615 | 3663 | 3711 | 48 |
| 899 | 95– | 3760 | 3808 | 3856 | 3905 | 3953 | 4001 | 4049 | 4098 | 4146 | 4194 | 48 |
| 900 | 95– | 4243 | 4291 | 4339 | 4387 | 4435 | 4484 | 4532 | 4580 | 4628 | 4677 | 48 |
| 901 | 95– | 4725 | 4773 | 4821 | 4869 | 4918 | 4966 | 5014 | 5062 | 5110 | 5158 | 48 |
| 902 | 95– | 5207 | 5255 | 5303 | 5351 | 5399 | 5447 | 5495 | 5543 | 5592 | 5640 | 48 |
| 903 | 95– | 5688 | 5736 | 5784 | 5832 | 5880 | 5928 | 5976 | 6024 | 6072 | 6120 | 48 |
| 904 | 95– | 6168 | 6216 | 6265 | 6313 | 6361 | 6409 | 6457 | 6505 | 6553 | 6601 | 48 |
| 905 | 95– | 6649 | 6697 | 6745 | 6793 | 6840 | 6888 | 6936 | 6984 | 7032 | 7080 | 48 |
| 906 | 95– | 7128 | 7176 | 7224 | 7272 | 7320 | 7368 | 7416 | 7464 | 7512 | 7559 | 48 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

LOGARITHMS OF NUMBERS FROM 1 TO 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 907 | 95– | 7607 | 7655 | 7703 | 7751 | 7799 | 7847 | 7894 | 7942 | 7990 | 8038 | 48 |
| 908 | 95– | 8086 | 8134 | 8181 | 8229 | 8277 | 8325 | 8373 | 8421 | 8468 | 8516 | 48 |
| 909 | 95– | 8564 | 8612 | 8659 | 8707 | 8755 | 8803 | 8850 | 8898 | 8946 | 8994 | 48 |
| 910 | 95– | 9041 | 9089 | 9137 | 9185 | 9232 | 9280 | 9328 | 9375 | 9423 | 9471 | 48 |
| 911 | 95– | 9518 | 9566 | 9614 | 9661 | 9709 | 9757 | 9804 | 9852 | 9900 | 9947 | 48 |
| 912 | 95– | 9995 | .... | .... | .... | .... | .... | .... | .... | .... | .... | 48 |
| 912 | 96– | .... | 0042 | 0090 | 0138 | 0185 | 0233 | 0280 | 0328 | 0376 | 0423 | 48 |
| 913 | 96– | 0471 | 0518 | 0566 | 0613 | 0661 | 0709 | 0756 | 0804 | 0851 | 0899 | 48 |
| 914 | 96– | 0946 | 0994 | 1041 | 1089 | 1136 | 1184 | 1231 | 1279 | 1326 | 1374 | 47 |
| 915 | 96– | 1421 | 1469 | 1516 | 1563 | 1611 | 1658 | 1706 | 1753 | 1801 | 1848 | 47 |
| 916 | 96– | 1895 | 1943 | 1990 | 2038 | 2085 | 2132 | 2180 | 2227 | 2275 | 2322 | 47 |
| 917 | 96– | 2369 | 2417 | 2464 | 2511 | 2559 | 2606 | 2653 | 2701 | 2748 | 2795 | 47 |
| 918 | 96– | 2843 | 2890 | 2937 | 2985 | 3032 | 3079 | 3126 | 3174 | 3221 | 3268 | 47 |
| 919 | 96– | 3316 | 3363 | 3410 | 3457 | 3504 | 3552 | 3599 | 3646 | 3693 | 3741 | 47 |
| 920 | 96– | 3788 | 3835 | 3882 | 3929 | 3977 | 4024 | 4071 | 4118 | 4165 | 4212 | 47 |
| 921 | 96– | 4260 | 4307 | 4354 | 4401 | 4448 | 4495 | 4542 | 4590 | 4637 | 4684 | 47 |
| 922 | 96– | 4731 | 4778 | 4825 | 4872 | 4919 | 4966 | 5013 | 5061 | 5108 | 5155 | 47 |
| 923 | 96– | 5202 | 5249 | 5296 | 5343 | 5390 | 5437 | 5484 | 5531 | 5578 | 5625 | 47 |
| 924 | 96– | 5672 | 5719 | 5766 | 5813 | 5860 | 5907 | 5954 | 6001 | 6048 | 6095 | 47 |
| 925 | 96– | 6142 | 6189 | 6236 | 6283 | 6329 | 6376 | 6423 | 6470 | 6517 | 6564 | 47 |
| 926 | 96– | 6611 | 6658 | 6705 | 6752 | 6799 | 6845 | 6892 | 6939 | 6986 | 7033 | 47 |
| 927 | 96– | 7080 | 7127 | 7173 | 7220 | 7267 | 7314 | 7361 | 7408 | 7454 | 7501 | 47 |
| 928 | 96– | 7548 | 7595 | 7642 | 7688 | 7735 | 7782 | 7829 | 7875 | 7922 | 7969 | 47 |
| 929 | 96– | 8016 | 8062 | 8109 | 8156 | 8203 | 8249 | 8296 | 8343 | 8390 | 8436 | 47 |
| 930 | 96– | 8483 | 8530 | 8576 | 8623 | 8670 | 8716 | 8763 | 8810 | 8856 | 8903 | 47 |
| 931 | 96– | 8950 | 8996 | 9043 | 9090 | 9136 | 9183 | 9229 | 9276 | 9323 | 9369 | 47 |
| 932 | 96– | 9416 | 9463 | 9509 | 9556 | 9602 | 9649 | 9695 | 9742 | 9789 | 9835 | 47 |
| 933 | 96– | 9882 | 9928 | 9975 | .... | .... | .... | .... | .... | .... | .... | 47 |
| 933 | 97– | .... | .... | .... | 0021 | 0068 | 0114 | 0161 | 0207 | 0254 | 0300 | 47 |
| 934 | 97– | 0347 | 0393 | 0440 | 0486 | 0533 | 0579 | 0626 | 0672 | 0719 | 0765 | 46 |
| 935 | 97– | 0812 | 0858 | 0904 | 0951 | 0997 | 1044 | 1090 | 1137 | 1183 | 1229 | 46 |
| 936 | 97– | 1276 | 1322 | 1369 | 1415 | 1461 | 1508 | 1554 | 1601 | 1647 | 1693 | 46 |
| 937 | 97– | 1740 | 1786 | 1832 | 1879 | 1925 | 1971 | 2018 | 2064 | 2110 | 2157 | 46 |
| 938 | 97– | 2203 | 2249 | 2295 | 2342 | 2388 | 2434 | 2481 | 2527 | 2573 | 2619 | 46 |
| 939 | 97– | 2666 | 2712 | 2758 | 2804 | 2851 | 2897 | 2943 | 2989 | 3035 | 3082 | 46 |
| 940 | 97– | 3128 | 3174 | 3220 | 3266 | 3313 | 3359 | 3405 | 3451 | 3497 | 3543 | 46 |
| 941 | 97– | 3590 | 3636 | 3682 | 3728 | 3774 | 3820 | 3866 | 3913 | 3959 | 4005 | 46 |
| 942 | 97– | 4051 | 4097 | 4143 | 4189 | 4235 | 4281 | 4327 | 4374 | 4420 | 4466 | 46 |
| 943 | 97– | 4512 | 4558 | 4604 | 4650 | 4696 | 4742 | 4788 | 4834 | 4880 | 4926 | 46 |
| 944 | 97– | 4972 | 5018 | 5064 | 5110 | 5156 | 5202 | 5248 | 5294 | 5340 | 5386 | 46 |
| 945 | 97– | 5432 | 5478 | 5524 | 5570 | 5616 | 5662 | 5707 | 5753 | 5799 | 5845 | 46 |
| 946 | 97– | 5891 | 5937 | 5983 | 6029 | 6075 | 6121 | 6167 | 6212 | 6258 | 6304 | 46 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

LOGARITHMS OF NUMBERS FROM 1 TO 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 947 | 97– | 6350 | 6396 | 6442 | 6488 | 6533 | 6579 | 6625 | 6671 | 6717 | 6763 | 46 |
| 948 | 97– | 6808 | 6854 | 6900 | 6946 | 6992 | 7037 | 7083 | 7129 | 7175 | 7220 | 46 |
| 949 | 97– | 7266 | 7312 | 7358 | 7403 | 7449 | 7495 | 7541 | 7586 | 7632 | 7678 | 46 |
| 950 | 97– | 7724 | 7769 | 7815 | 7861 | 7906 | 7952 | 7998 | 8043 | 8089 | 8135 | 46 |
| 951 | 97– | 8181 | 8226 | 8272 | 8317 | 8363 | 8409 | 8454 | 8500 | 8546 | 8591 | 46 |
| 952 | 97– | 8637 | 8683 | 8728 | 8774 | 8819 | 8865 | 8911 | 8956 | 9002 | 9047 | 46 |
| 953 | 97– | 9093 | 9138 | 9184 | 9230 | 9275 | 9321 | 9366 | 9412 | 9457 | 9503 | 46 |
| 954 | 97– | 9548 | 9594 | 9639 | 9685 | 9730 | 9776 | 9821 | 9867 | 9912 | 9958 | 46 |
| 955 | 98– | 0003 | 0049 | 0094 | 0140 | 0185 | 0231 | 0276 | 0322 | 0367 | 0412 | 45 |
| 956 | 98– | 0458 | 0503 | 0549 | 0594 | 0640 | 0685 | 0730 | 0776 | 0821 | 0867 | 45 |
| 957 | 98– | 0912 | 0957 | 1003 | 1048 | 1093 | 1139 | 1184 | 1229 | 1275 | 1320 | 45 |
| 958 | 98– | 1366 | 1411 | 1456 | 1501 | 1547 | 1592 | 1637 | 1683 | 1728 | 1773 | 45 |
| 959 | 98– | 1819 | 1864 | 1909 | 1954 | 2000 | 2045 | 2090 | 2135 | 2181 | 2226 | 45 |
| 960 | 98– | 2271 | 2316 | 2362 | 2407 | 2452 | 2497 | 2543 | 2588 | 2633 | 2678 | 45 |
| 961 | 98– | 2723 | 2769 | 2814 | 2859 | 2904 | 2949 | 2994 | 3040 | 3085 | 3130 | 45 |
| 962 | 98– | 3175 | 3220 | 3265 | 3310 | 3356 | 3401 | 3446 | 3491 | 3536 | 3581 | 45 |
| 963 | 98– | 3626 | 3671 | 3716 | 3762 | 3807 | 3852 | 3897 | 3942 | 3987 | 4032 | 45 |
| 964 | 98– | 4077 | 4122 | 4167 | 4212 | 4257 | 4302 | 4347 | 4392 | 4437 | 4482 | 45 |
| 965 | 98– | 4527 | 4572 | 4617 | 4662 | 4707 | 4752 | 4797 | 4842 | 4887 | 4932 | 45 |
| 966 | 98– | 4977 | 5022 | 5067 | 5112 | 5157 | 5202 | 5247 | 5292 | 5337 | 5382 | 45 |
| 967 | 98– | 5426 | 5471 | 5516 | 5561 | 5606 | 5651 | 5696 | 5741 | 5786 | 5830 | 45 |
| 968 | 98– | 5875 | 5920 | 5965 | 6010 | 6055 | 6100 | 6144 | 6189 | 6234 | 6279 | 45 |
| 969 | 98– | 6324 | 6369 | 6413 | 6458 | 6503 | 6548 | 6593 | 6637 | 6682 | 6727 | 45 |
| 970 | 98– | 6772 | 6817 | 6861 | 6906 | 6951 | 6996 | 7040 | 7085 | 7130 | 7175 | 45 |
| 971 | 98– | 7219 | 7264 | 7309 | 7353 | 7398 | 7443 | 7488 | 7532 | 7577 | 7622 | 45 |
| 972 | 98– | 7666 | 7711 | 7756 | 7800 | 7845 | 7890 | 7934 | 7979 | 8024 | 8068 | 45 |
| 973 | 98– | 8113 | 8157 | 8202 | 8247 | 8291 | 8336 | 8381 | 8425 | 8470 | 8514 | 45 |
| 974 | 98– | 8559 | 8604 | 8648 | 8693 | 8737 | 8782 | 8826 | 8871 | 8916 | 8960 | 45 |
| 975 | 98– | 9005 | 9049 | 9094 | 9138 | 9183 | 9227 | 9272 | 9316 | 9361 | 9405 | 45 |
| 976 | 98– | 9450 | 9494 | 9539 | 9583 | 9628 | 9672 | 9717 | 9761 | 9806 | 9850 | 44 |
| 977 | 98– | 9895 | 9939 | 9983 | .... | .... | .... | .... | .... | .... | .... | 44 |
| 977 | 99– | .... | .... | .... | 0028 | 0072 | 0117 | 0161 | 0206 | 0250 | 0294 | 44 |
| 978 | 99– | 0339 | 0383 | 0428 | 0472 | 0516 | 0561 | 0605 | 0650 | 0694 | 0738 | 44 |
| 979 | 99– | 0783 | 0827 | 0871 | 0916 | 0960 | 1004 | 1049 | 1093 | 1137 | 1182 | 44 |
| 980 | 99– | 1226 | 1270 | 1315 | 1359 | 1403 | 1448 | 1492 | 1536 | 1580 | 1625 | 44 |
| 981 | 99– | 1669 | 1713 | 1758 | 1802 | 1846 | 1890 | 1935 | 1979 | 2023 | 2067 | 44 |
| 982 | 99– | 2111 | 2156 | 2200 | 2244 | 2288 | 2333 | 2377 | 2421 | 2465 | 2509 | 44 |
| 983 | 99– | 2554 | 2598 | 2642 | 2686 | 2730 | 2774 | 2819 | 2863 | 2907 | 2951 | 44 |
| 984 | 99– | 2995 | 3039 | 3083 | 3127 | 3172 | 3216 | 3260 | 3304 | 3348 | 3392 | 44 |
| 985 | 99– | 3436 | 3480 | 3524 | 3568 | 3613 | 3657 | 3701 | 3745 | 3789 | 3833 | 44 |
| 986 | 99– | 3877 | 3921 | 3965 | 4009 | 4053 | 4097 | 4141 | 4185 | 4229 | 4273 | 44 |
| 987 | 99– | 4317 | 4361 | 4405 | 4449 | 4493 | 4537 | 4581 | 4625 | 4669 | 4713 | 44 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

LOGARITHMS OF NUMBERS FROM 1 TO 1000—(*Cont.*)

| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 988 | 99- | 4757 | 4801 | 4845 | 4889 | 4933 | 4977 | 5021 | 5065 | 5108 | 5152 | 44 |
| 989 | 99- | 5196 | 5240 | 5284 | 5328 | 5372 | 5416 | 5460 | 5504 | 5547 | 5591 | 44 |
| 990 | 99- | 5635 | 5679 | 5723 | 5767 | 5811 | 5854 | 5898 | 5942 | 5986 | 6030 | 44 |
| 991 | 99- | 6074 | 6117 | 6161 | 6205 | 6249 | 6293 | 6337 | 6380 | 6424 | 6468 | 44 |
| 992 | 99- | 6512 | 6555 | 6599 | 6643 | 6687 | 6731 | 6774 | 6818 | 6862 | 6906 | 44 |
| 993 | 99- | 6949 | 6993 | 7037 | 7080 | 7124 | 7168 | 7212 | 7255 | 7299 | 7343 | 44 |
| 994 | 99- | 7386 | 7430 | 7474 | 7517 | 7561 | 7605 | 7648 | 7692 | 7736 | 7779 | 44 |
| 995 | 99- | 7823 | 7867 | 7910 | 7954 | 7998 | 8041 | 8085 | 8129 | 8172 | 8216 | 44 |
| 996 | 99- | 8259 | 8303 | 8347 | 8390 | 8434 | 8477 | 8521 | 8564 | 8608 | 8652 | 44 |
| 997 | 99- | 8695 | 8739 | 8782 | 8826 | 8869 | 8913 | 8956 | 9000 | 9043 | 9087 | 44 |
| 998 | 99- | 9131 | 9174 | 9218 | 9261 | 9305 | 9348 | 9392 | 9435 | 9479 | 9522 | 44 |
| 999 | 99- | 9565 | 9609 | 9652 | 9696 | 9739 | 9783 | 9826 | 9870 | 9913 | 9957 | 43 |
| N | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D |

## HYPERBOLIC LOGARITHMS

In the Naperian or hyperbolic system of logarithms, the base is 2.718281828.

The Naperian base is commonly denoted by $e$, as in the equation $e^y = x$, in which $y$ is the Naperian logarithm of $x$. The abbreviation $\log_e$ is commonly used to denote the Naperian logarithm.

In any system of logarithms, the logarithm of 1 is 0; the logarithm of the base taken in that system is 1. In any system the base of which is greater than 1, the logarithms of all numbers greater than 1 are positive, and the logarithms of all numbers less than 1 are negative.

The modulus of any system is equal to the reciprocal of the Naperian logarithm of the base of that system. The modulus of the Naperian system is 1, that of the common system, 0.4342945.

The logarithm of a number in any system equals the modulus of that system $\times$ the Naperian logarithm of the number.

The hyperbolic or Naperian logarithm of any number equals the common logarithm $\times$ 2.3025851.

Base of Naperian system $e$ = constant 0.718281828
logarithm 0.4342945.

Reciprocal of modulus $k$ = constant 2.302585093.
logarithm 0.3622216.

## TABLE OF HYPERBOLIC LOGARITHMS

The hyperbolic logarithms of numbers, or Naperian logarithms, as they are sometimes called, are calculated by multiplying the common logarithm of the given numbers in the table of common logarithms by the constant multiplier, 2.302585.

The hyperbolic logarithms of numbers intermediate between those which are given in the table may be readily obtained by interpolating proportional differences.

## Hyperbolic Logarithms of Numbers from 1 to 30

| Number | Logarithm | Number | Logarithm | Number | Logarithm | Number | Logarithm |
|---|---|---|---|---|---|---|---|
| 1.01 | .0099 | 1.46 | .3784 | 1.91 | .6471 | 2.36 | .8587 |
| 1.02 | .0198 | 1.47 | .3853 | 1.92 | .6523 | 2.37 | .8629 |
| 1.03 | .0296 | 1.48 | .3920 | 1.93 | .6575 | 2.38 | .8671 |
| 1.04 | .0392 | 1.49 | .3988 | 1.94 | .6627 | 2.39 | .8713 |
| 1.05 | .0488 | 1.50 | .4055 | 1.95 | .6678 | 2.40 | .8755 |
| 1.06 | .0583 | 1.51 | .4121 | 1.96 | .6729 | 2.41 | .8796 |
| 1.07 | .0677 | 1.52 | .4187 | 1.97 | .6780 | 2.42 | .8838 |
| 1.08 | .0770 | 1.53 | .4253 | 1.98 | .6831 | 2.43 | .8879 |
| 1.09 | .0862 | 1.54 | .4318 | 1.99 | .6881 | 2.44 | .8920 |
| 1.10 | .0953 | 1.55 | .4383 | 2.00 | .6931 | 2.45 | .8961 |
| 1.11 | .1044 | 1.56 | .4447 | 2.01 | .6981 | 2.46 | .9002 |
| 1.12 | .1133 | 1.57 | .4511 | 2.02 | .7031 | 2.47 | .9042 |
| 1.13 | .1222 | 1.58 | .4574 | 2.03 | .7080 | 2.48 | .9083 |
| 1.14 | .1310 | 1.59 | .4637 | 2.04 | .7129 | 2.49 | .9123 |
| 1.15 | .1398 | 1.60 | .4700 | 2.05 | .7178 | 2.50 | .9163 |
| 1.16 | .1484 | 1.61 | .4762 | 2.06 | .7227 | 2.51 | .9203 |
| 1.17 | .1570 | 1.62 | .4824 | 2.07 | .7275 | 2.52 | .9243 |
| 1.18 | .1655 | 1.63 | .4886 | 2.08 | .7324 | 2.53 | .9282 |
| 1.19 | .1740 | 1.64 | .4947 | 2.09 | .7372 | 2.54 | .9322 |
| 1.20 | .1823 | 1.65 | .5008 | 2.10 | .7419 | 2.55 | .9361 |
| 1.21 | .1906 | 1.66 | .5068 | 2.11 | .7467 | 2.56 | .9400 |
| 1.22 | .1988 | 1.67 | .5128 | 2.12 | .7514 | 2.57 | .9439 |
| 1.23 | .2070 | 1.68 | .5188 | 2.13 | .7561 | 2.58 | .9478 |
| 1.24 | .2151 | 1.69 | .5247 | 2.14 | .7608 | 2.59 | .9517 |
| 1.25 | .2231 | 1.70 | .5306 | 2.15 | .7655 | 2.60 | .9555 |
| 1.26 | .2311 | 1.71 | .5365 | 2.16 | .7701 | 2.61 | .9594 |
| 1.27 | .2390 | 1.72 | .5423 | 2.17 | .7747 | 2.62 | .9632 |
| 1.28 | .2469 | 1.73 | .5481 | 2.18 | .7793 | 2.63 | .9670 |
| 1.29 | .2546 | 1.74 | .5539 | 2.19 | .7839 | 2.64 | .9708 |
| 1.30 | .2624 | 1.75 | .5596 | 2.20 | .7885 | 2.65 | .9746 |
| 1.31 | .2700 | 1.76 | .5653 | 2.21 | .7930 | 2.66 | .9783 |
| 1.32 | .2776 | 1.77 | .5710 | 2.22 | .7975 | 2.67 | .9821 |
| 1.33 | .2852 | 1.78 | .5766 | 2.23 | .8020 | 2.68 | .9858 |
| 1.34 | .2927 | 1.79 | .5822 | 2.24 | .8065 | 2.69 | .9895 |
| 1.35 | .3001 | 1.80 | .5878 | 2.25 | .8109 | 2.70 | .9933 |
| 1.36 | .3075 | 1.81 | .5933 | 2.26 | .8154 | 2.71 | .9969 |
| 1.37 | .3148 | 1.82 | .5988 | 2.27 | .8198 | 2.72 | 1.0006 |
| 1.38 | .3221 | 1.83 | .6043 | 2.28 | .8242 | 2.73 | 1.0043 |
| 1.39 | .3293 | 1.84 | .6098 | 2.29 | .8286 | 2.74 | 1.0080 |
| 1.40 | .3365 | 1.85 | .6152 | 2.30 | .8329 | 2.75 | 1.0116 |
| 1.41 | .3436 | 1.86 | .6206 | 2.31 | .8372 | 2.76 | 1.0152 |
| 1.42 | 3507 | 1.87 | .6259 | 2.32 | .8416 | 2.77 | 1.0188 |
| 1.43 | 3577 | 1.88 | .6313 | 2.33 | .8458 | 2.78 | 1.0225 |
| 1.44 | .3646 | 1.89 | .6366 | 2.34 | .8502 | 2.79 | 1.0260 |
| 1.45 | .3716 | 1.90 | .6419 | 2.35 | .8544 | 2.80 | 1.0296 |

HYPERBOLIC LOGARITHMS OF NUMBERS FROM 1 TO 30—(*Cont.*)

| Number | Logarithm | Number | Logarithm | Number | Logarithm | Number | Logarithm |
|---|---|---|---|---|---|---|---|
| 2.81 | 1.0332 | 3.26 | 1.1817 | 3.71 | 1.3110 | 4.16 | 1.4255 |
| 2.82 | 1.0367 | 3.27 | 1.1848 | 3.72 | 1.3137 | 4.17 | 1.4279 |
| 2.83 | 1.0403 | 3.28 | 1.1878 | 3.73 | 1.3164 | 4.18 | 1.4303 |
| 2.84 | 1.0438 | 3.29 | 1.1909 | 3.74 | 1.3191 | 4.19 | 1.4327 |
| 2.85 | 1.0473 | 3.30 | 1.1939 | 3.75 | 1.3218 | 4.20 | 1.4351 |
| 2.86 | 1.0508 | 3.31 | 1.1969 | 3.76 | 1.3244 | 4.21 | 1.4375 |
| 2.87 | 1.0543 | 3.32 | 1.1999 | 3.77 | 1.3271 | 4.22 | 1.4398 |
| 2.88 | 1.0578 | 3.33 | 1.2030 | 3.78 | 1.3297 | 4.23 | 1.4422 |
| 2.89 | 1.0613 | 3.34 | 1.2060 | 3.79 | 1.3324 | 4.24 | 1.4446 |
| 2.90 | 1.0647 | 3.35 | 1.2090 | 3.80 | 1.3350 | 4.25 | 1.4469 |
| 2.91 | 1.0682 | 3.36 | 1.2119 | 3.81 | 1.3376 | 4.26 | 1.4493 |
| 2.92 | 1.0716 | 3.37 | 1.2149 | 3.82 | 1.3403 | 4.27 | 1.4516 |
| 2.93 | 1.0750 | 3.38 | 1.2179 | 3.83 | 1.3429 | 4.28 | 1.4540 |
| 2.94 | 1.0784 | 3.39 | 1.2208 | 3.84 | 1.3455 | 4.29 | 1.4563 |
| 2.95 | 1.0818 | 3.40 | 1.2238 | 3.85 | 1.3481 | 4.30 | 1.4586 |
| 2.96 | 1.0852 | 3.41 | 1.2267 | 3.86 | 1.3507 | 4.31 | 1.4609 |
| 2.97 | 1.0886 | 3.42 | 1.2296 | 3.87 | 1.3533 | 4.32 | 1.4633 |
| 2.98 | 1.0919 | 3.43 | 1.2326 | 3.88 | 1.3558 | 4.33 | 1.4656 |
| 2.99 | 1.0953 | 3.44 | 1.2355 | 3.89 | 1.3584 | 4.34 | 1.4679 |
| 3.00 | 1.0986 | 3.45 | 1.2384 | 3.90 | 1.3610 | 4.35 | 1.4702 |
| 3.01 | 1.1019 | 3.46 | 1.2413 | 3.91 | 1.3635 | 4.36 | 1.4725 |
| 3.02 | 1.1053 | 3.47 | 1.2442 | 3.92 | 1.3661 | 4.37 | 1.4748 |
| 3.03 | 1.1086 | 3.48 | 1.2470 | 3.93 | 1.3686 | 4.38 | 1.4770 |
| 3.04 | 1.1119 | 3.49 | 1.2499 | 3.94 | 1.3712 | 4.39 | 1.4793 |
| 3.05 | 1.1151 | 3.50 | 1.2528 | 3.95 | 1.3737 | 4.40 | 1.4816 |
| 3.06 | 1.1184 | 3.51 | 1.2556 | 3.96 | 1.3762 | 4.41 | 1.4839 |
| 3.07 | 1.1217 | 3.52 | 1.2585 | 3.97 | 1.3788 | 4.42 | 1.4861 |
| 3.08 | 1.1249 | 3.53 | 1.2613 | 3.98 | 1.3813 | 4.43 | 1.4884 |
| 3.09 | 1.1282 | 3.54 | 1.2641 | 3.99 | 1.3838 | 4.44 | 1.4907 |
| 3.10 | 1.1314 | 3.55 | 1.2669 | 4.00 | 1.3863 | 4.45 | 1.4929 |
| 3.11 | 1.1346 | 3.56 | 1.2698 | 4.01 | 1.3888 | 4.46 | 1.4951 |
| 3.12 | 1.1378 | 3.57 | 1.2726 | 4.02 | 1.3913 | 4.47 | 1.4974 |
| 3.13 | 1.1410 | 3.58 | 1.2754 | 4.03 | 1.3938 | 4.48 | 1.4996 |
| 3.14 | 1.1442 | 3.59 | 1.2782 | 4.04 | 1.3962 | 4.49 | 1.5019 |
| 3.15 | 1.1474 | 3.60 | 1.2809 | 4.05 | 1.3987 | 4.50 | 1.5041 |
| 3.16 | 1.1506 | 3.61 | 1.2837 | 4.06 | 1.4012 | 4.51 | 1.5063 |
| 3.17 | 1.1537 | 3.62 | 1.2865 | 4.07 | 1.4036 | 4.52 | 1.5085 |
| 3.18 | 1.1569 | 3.63 | 1.2892 | 4.08 | 1.4061 | 4.53 | 1.5107 |
| 3.19 | 1.1600 | 3.64 | 1.2920 | 4.09 | 1.4085 | 4.54 | 1.5129 |
| 3.20 | 1.1632 | 3.65 | 1.2947 | 4.10 | 1.4110 | 4.55 | 1.5151 |
| 3.21 | 1.1663 | 3.66 | 1.2975 | 4.11 | 1.4134 | 4.56 | 1.5173 |
| 3.22 | 1.1694 | 3.67 | 1.3002 | 4.12 | 1.4159 | 4.57 | 1.5195 |
| 3.23 | 1.1725 | 3.68 | 1.3029 | 4.13 | 1.4183 | 4.58 | 1.5217 |
| 3.24 | 1.1756 | 3.69 | 1.3056 | 4.14 | 1.4207 | 4.59 | 1.5239 |
| 3.25 | 1.1787 | 3.70 | 1.3083 | 4.15 | 1.4231 | 4.60 | 1.5261 |

HYPERBOLIC LOGARITHMS OF NUMBERS FROM 1 TO 30—(*Cont.*)

| Number | Logarithm | Number | Logarithm | Number | Logarithm | Number | Logarithm |
|---|---|---|---|---|---|---|---|
| 4.61 | 1.5282 | 5.06 | 1.6214 | 5.51 | 1.7066 | 5.96 | 1.7851 |
| 4.62 | 1.5304 | 5.07 | 1.6233 | 5.52 | 1.7084 | 5.97 | 1.7867 |
| 4.63 | 1.5326 | 5.08 | 1.6253 | 5.53 | 1.7102 | 5.98 | 1.7884 |
| 4.64 | 1.5347 | 5.09 | 1.6273 | 5.54 | 1.7120 | 5.99 | 1.7901 |
| 4.65 | 1.5369 | 5.10 | 1.6292 | 5.55 | 1.7138 | 6.00 | 1.7918 |
| 4.66 | 1.5390 | 5.11 | 1.6312 | 5.56 | 1.7156 | 6.01 | 1.7934 |
| 4.67 | 1.5412 | 5.12 | 1.6332 | 5.57 | 1.7174 | 6.02 | 1.7951 |
| 4.68 | 1.5433 | 5.13 | 1.6351 | 5.58 | 1.7192 | 6.03 | 1.7967 |
| 4.69 | 1.5454 | 5.14 | 1.6371 | 5.59 | 1.7210 | 6.04 | 1.7984 |
| 4.70 | 1.5476 | 5.15 | 1.6390 | 5.60 | 1.7228 | 6.05 | 1.8001 |
| 4.71 | 1.5497 | 5.16 | 1.6409 | 5.61 | 1.7246 | 6.06 | 1.8017 |
| 4.72 | 1.5518 | 5.17 | 1.6429 | 5.62 | 1.7263 | 6.07 | 1.8034 |
| 4.73 | 1.5539 | 5.18 | 1.6448 | 5.63 | 1.7281 | 6.08 | 1.8050 |
| 4.74 | 1.5560 | 5.19 | 1.6467 | 5.64 | 1.7299 | 6.09 | 1.8066 |
| 4.75 | 1.5581 | 5.20 | 1.6487 | 5.65 | 1.7317 | 6.10 | 1.8083 |
| 4.76 | 1.5602 | 5.21 | 1.6506 | 5.66 | 1.7334 | 6.11 | 1.8099 |
| 4.77 | 1.5623 | 5.22 | 1.6525 | 5.67 | 1.7352 | 6.12 | 1.8116 |
| 4.78 | 1.5644 | 5.23 | 1.6544 | 5.68 | 1.7370 | 6.13 | 1.8132 |
| 4.79 | 1.5665 | 5.24 | 1.6563 | 5.69 | 1.7387 | 6.14 | 1.8148 |
| 4.80 | 1.5686 | 5.25 | 1.6582 | 5.70 | 1.7405 | 6.15 | 1.8165 |
| 4.81 | 1.5707 | 5.26 | 1.6601 | 5.71 | 1.7422 | 6.16 | 1.8181 |
| 4.82 | 1.5728 | 5.27 | 1.6620 | 5.72 | 1.7440 | 6.17 | 1.8197 |
| 4.83 | 1.5748 | 5.28 | 1.6639 | 5.73 | 1.7457 | 6.18 | 1.8213 |
| 4.84 | 1.5769 | 5.29 | 1.6658 | 5.74 | 1.7475 | 6.19 | 1.8229 |
| 4.85 | 1.5790 | 5.30 | 1.6677 | 5.75 | 1.7492 | 6.20 | 1.8245 |
| 4.86 | 1.5810 | 5.31 | 1.6696 | 5.76 | 1.7509 | 6.21 | 1.8262 |
| 4.87 | 1.5831 | 5.32 | 1.6715 | 5.77 | 1.7527 | 6.22 | 1.8278 |
| 4.88 | 1.5851 | 5.33 | 1.6734 | 5.78 | 1.7544 | 6.23 | 1.8294 |
| 4.89 | 1.5872 | 5.34 | 1.6752 | 5.79 | 1.7561 | 6.24 | 1.8310 |
| 4.90 | 1.5892 | 5.35 | 1.6771 | 5.80 | 1.7579 | 6.25 | 1.8326 |
| 4.91 | 1.5913 | 5.36 | 1.6790 | 5.81 | 1.7596 | 6.26 | 1.8342 |
| 4.92 | 1.5933 | 5.37 | 1.6808 | 5.82 | 1.7613 | 6.27 | 1.8358 |
| 4.93 | 1.5953 | 5.38 | 1.6827 | 5.83 | 1.7630 | 6.28 | 1.8374 |
| 4.94 | 1.5974 | 5.39 | 1.6845 | 5.84 | 1.7647 | 6.29 | 1.8390 |
| 4.95 | 1.5994 | 5.40 | 1.6864 | 5.85 | 1.7664 | 6.30 | 1.8405 |
| 4.96 | 1.6014 | 5.41 | 1.6882 | 5.86 | 1.7681 | 6.31 | 1.8421 |
| 4.97 | 1.6034 | 5.42 | 1.6901 | 5.87 | 1.7699 | 6.32 | 1.8437 |
| 4.98 | 1.6054 | 5.43 | 1.6919 | 5.88 | 1.7716 | 6.33 | 1.8453 |
| 4.99 | 1.6074 | 5.44 | 1.6938 | 5.89 | 1.7733 | 6.34 | 1.8469 |
| 5.00 | 1.6094 | 5.45 | 1.6956 | 5.90 | 1.7750 | 6.35 | 1.8485 |
| 5.01 | 1.6114 | 5.46 | 1.6974 | 5.91 | 1.7766 | 6.36 | 1.8500 |
| 5.02 | 1.6134 | 5.47 | 1.6993 | 5.92 | 1.7783 | 6.37 | 1.8516 |
| 5.03 | 1.6154 | 5.48 | 1.7011 | 5.93 | 1.7800 | 6.38 | 1.8532 |
| 5.04 | 1.6174 | 5.49 | 1.7029 | 5.94 | 1.7817 | 6.39 | 1.8547 |
| 5.05 | 1.6194 | 5.50 | 1.7047 | 5.95 | 1.7834 | 6.40 | 1.8563 |

HYPERBOLIC LOGARITHMS OF NUMBERS FROM 1 TO 30—(*Cont.*)

| Number | Logarithm | Number | Logarithm | Number | Logarithm | Number | Logarithm |
|---|---|---|---|---|---|---|---|
| 6.41 | 1.8579 | 6.86 | 1.9257 | 7.31 | 1.9892 | 7.76 | 2.0490 |
| 6.42 | 1.8594 | 6.87 | 1.9272 | 7.32 | 1.9906 | 7.77 | 2.0503 |
| 6.43 | 1.8610 | 6.88 | 1.9286 | 7.33 | 1.9920 | 7.78 | 2.0516 |
| 6.44 | 1.8625 | 6.89 | 1.9301 | 7.34 | 1.9933 | 7.79 | 2.0528 |
| 6.45 | 1.8641 | 6.90 | 1.9315 | 7.35 | 1.9947 | 7.80 | 2.0541 |
| 6.46 | 1.8656 | 6.91 | 1.9330 | 7.36 | 1.9961 | 7.81 | 2.0554 |
| 6.47 | 1.8672 | 6.92 | 1.9344 | 7.37 | 1.9974 | 7.82 | 2.0567 |
| 6.48 | 1.8687 | 6.93 | 1.9359 | 7.38 | 1.9988 | 7.83 | 2.0580 |
| 6.49 | 1.8703 | 6.94 | 1.9373 | 7.39 | 2.0001 | 7.84 | 2.0592 |
| 6.50 | 1.8718 | 6.95 | 1.9387 | 7.40 | 2.0015 | 7.85 | 2.0605 |
| 6.51 | 1.8733 | 6.96 | 1.9402 | 7.41 | 2.0028 | 7.86 | 2.0618 |
| 6.52 | 1.8749 | 6.97 | 1.9416 | 7.42 | 2.0042 | 7.87 | 2.0631 |
| 6.53 | 1.8764 | 6.98 | 1.9430 | 7.43 | 2.0055 | 7.88 | 2.0643 |
| 6.54 | 1.8779 | 6.99 | 1.9445 | 7.44 | 2.0069 | 7.89 | 2.0656 |
| 6.55 | 1.8795 | 7.00 | 1.9459 | 7.45 | 2.0082 | 7.90 | 2.0669 |
| 6.56 | 1.8810 | 7.01 | 1.9473 | 7.46 | 2.0096 | 7.91 | 2.0681 |
| 6.57 | 1.8825 | 7.02 | 1.9488 | 7.47 | 2.0109 | 7.92 | 2.0694 |
| 6.58 | 1.8840 | 7.03 | 1.9502 | 7.48 | 2.0122 | 7.93 | 2.0707 |
| 6.59 | 1.8856 | 7.04 | 1.9516 | 7.49 | 2.0136 | 7.94 | 2.0719 |
| 6.60 | 1.8871 | 7.05 | 1.9530 | 7.50 | 2.0149 | 7.95 | 2.0732 |
| 6.61 | 1.8886 | 7.06 | 1.9544 | 7.51 | 2.0162 | 7.96 | 2.0744 |
| 6.62 | 1.8901 | 7.07 | 1.9559 | 7.52 | 2.0176 | 7.97 | 2.0757 |
| 6.63 | 1.8916 | 7.08 | 1.9573 | 7.53 | 2.0189 | 7.98 | 2.0769 |
| 6.64 | 1.8931 | 7.09 | 1.9587 | 7.54 | 2.0202 | 7.99 | 2.0782 |
| 6.65 | 1.8946 | 7.10 | 1.9601 | 7.55 | 2.0215 | 8.00 | 2.0794 |
| 6.66 | 1.8961 | 7.11 | 1.9615 | 7.56 | 2.0229 | 8.01 | 2.0807 |
| 6.67 | 1.8976 | 7.12 | 1.9629 | 7.57 | 2.0242 | 8.02 | 2.0819 |
| 6.68 | 1.8991 | 7.13 | 1.9643 | 7.58 | 2.0255 | 8.03 | 2.0832 |
| 6.69 | 1.9006 | 7.14 | 1.9657 | 7.59 | 2.0268 | 8.04 | 2.0844 |
| 6.70 | 1.9021 | 7.15 | 1.9671 | 7.60 | 2.0281 | 8.05 | 2.0857 |
| 6.71 | 1.9036 | 7.16 | 1.9685 | 7.61 | 2.0295 | 8.06 | 2.0869 |
| 6.72 | 1.9051 | 7.17 | 1.9699 | 7.62 | 2.0308 | 8.07 | 2.0882 |
| 6.73 | 1.9066 | 7.18 | 1.9713 | 7.63 | 2.0321 | 8.08 | 2.0894 |
| 6.74 | 1.9081 | 7.19 | 1.9727 | 7.64 | 2.0334 | 8.09 | 2.0906 |
| 6.75 | 1.9095 | 7.20 | 1.9741 | 7.65 | 2.0347 | 8.10 | 2.0919 |
| 6.76 | 1.9110 | 7.21 | 1.9755 | 7.66 | 2.0360 | 8.11 | 2.0931 |
| 6.77 | 1.9125 | 7.22 | 1.9769 | 7.67 | 2.0373 | 8.12 | 2.0943 |
| 6.78 | 1.9140 | 7.23 | 1.9782 | 7.68 | 2.0386 | 8.13 | 2.0956 |
| 6.79 | 1.9155 | 7.24 | 1.9796 | 7.69 | 2.0399 | 8.14 | 2.0968 |
| 6.80 | 1.9169 | 7.25 | 1.9810 | 7.70 | 2.0412 | 8.15 | 2.0980 |
| 6.81 | 1.9184 | 7.26 | 1.9824 | 7.71 | 2.0425 | 8.16 | 2.0992 |
| 6.82 | 1.9199 | 7.27 | 1.9838 | 7.72 | 2.0438 | 8.17 | 2.1005 |
| 6.83 | 1.9213 | 7.28 | 1.9851 | 7.73 | 2.0451 | 8.18 | 2.1017 |
| 6.84 | 1.9228 | 7.29 | 1.9865 | 7.74 | 2.0464 | 8.19 | 2.1029 |
| 6.85 | 1.9242 | 7.30 | 1.9879 | 7.75 | 2.0477 | 8.20 | 2.1041 |

HYPERBOLIC LOGARITHMS OF NUMBERS FROM 1 TO 30—(*Cont.*)

| Number | Logarithm | Number | Logarithm | Number | Logarithm | Number | Logarithm |
|---|---|---|---|---|---|---|---|
| 8.21 | 2.1054 | 8.66 | 2.1587 | 9.11 | 2.2094 | 9.56 | 2.2576 |
| 8.22 | 2.1066 | 8.67 | 2.1599 | 9.12 | 2.2105 | 9.57 | 2.2586 |
| 8.23 | 2.1078 | 8.68 | 2.1610 | 9.13 | 2.2116 | 9.58 | 2.2597 |
| 8.24 | 2.1090 | 8.69 | 2.1622 | 9.14 | 2.2127 | 9.59 | 2.2607 |
| 8.25 | 2.1102 | 8.70 | 2.1633 | 9.15 | 2.2138 | 9.60 | 2.2618 |
| 8.26 | 2.1114 | 8.71 | 2.1645 | 9.16 | 2.2148 | 9.61 | 2.2628 |
| 8.27 | 2.1126 | 8.72 | 2.1656 | 9.17 | 2.2159 | 9.62 | 2.2638 |
| 8.28 | 2.1138 | 8.73 | 2.1668 | 9.18 | 2.2170 | 9.63 | 2.2649 |
| 8.29 | 2.1150 | 8.74 | 2.1679 | 9.19 | 2.2181 | 9.64 | 2.2659 |
| 8.30 | 2.1163 | 8.75 | 2.1691 | 9.20 | 2.2192 | 9.65 | 2.2670 |
| 8.31 | 2.1175 | 8.76 | 2.1702 | 9.21 | 2.2203 | 9.66 | 2.2680 |
| 8.32 | 2.1187 | 8.77 | 2.1713 | 9.22 | 2.2214 | 9.67 | 2.2690 |
| 8.33 | 2.1199 | 8.78 | 2.1725 | 9.23 | 2.2225 | 9.68 | 2.2701 |
| 8.34 | 2.1211 | 8.79 | 2.1736 | 9.24 | 2.2235 | 9.69 | 2.2711 |
| 8.35 | 2.1223 | 8.80 | 2.1748 | 9.25 | 2.2246 | 9.70 | 2.2721 |
| 8.36 | 2.1235 | 8.81 | 2.1759 | 9.26 | 2.2257 | 9.71 | 2.2732 |
| 8.37 | 2.1247 | 8.82 | 2.1770 | 9.27 | 2.2268 | 9.72 | 2.2742 |
| 8.38 | 2.1258 | 8.83 | 2.1782 | 9.28 | 2.2279 | 9.73 | 2.2752 |
| 8.39 | 2.1270 | 8.84 | 2.1793 | 9.29 | 2.2289 | 9.74 | 2.2762 |
| 8.40 | 2.1282 | 8.85 | 2.1804 | 9.30 | 2.2300 | 9.75 | 2.2773 |
| 8.41 | 2.1294 | 8.86 | 2.1815 | 9.31 | 2.2311 | 9.76 | 2.2783 |
| 8.42 | 2.1306 | 8.87 | 2.1827 | 9.32 | 2.2322 | 9.77 | 2.2793 |
| 8.43 | 2.1318 | 8.88 | 2.1838 | 9.33 | 2.2332 | 9.78 | 2.2803 |
| 8.44 | 2.1330 | 8.89 | 2.1849 | 9.34 | 2.2343 | 9.79 | 2.2814 |
| 8.45 | 2.1342 | 8.90 | 2.1861 | 9.35 | 2.2354 | 9.80 | 2.2824 |
| 8.46 | 2.1353 | 8.91 | 2.1872 | 9.36 | 2.2364 | 9.81 | 2.2834 |
| 8.47 | 2.1365 | 8.92 | 2.1883 | 9.37 | 2.2375 | 9.82 | 2.2844 |
| 8.48 | 2.1377 | 8.93 | 2.1894 | 9.38 | 2.2386 | 9.83 | 2.2854 |
| 8.49 | 2.1389 | 8.94 | 2.1905 | 9.39 | 2.2396 | 9.84 | 2.2865 |
| 8.50 | 2.1401 | 8.95 | 2.1917 | 9.40 | 2.2407 | 9.85 | 2.2875 |
| 8.51 | 2.1412 | 8.96 | 2.1928 | 9.41 | 2.2418 | 9.86 | 2.2885 |
| 8.52 | 2.1424 | 8.97 | 2.1939 | 9.42 | 2.2428 | 9.87 | 2.2895 |
| 8.53 | 2.1436 | 8.98 | 2.1950 | 9.43 | 2.2439 | 9.88 | 2.2905 |
| 8.54 | 2.1448 | 8.99 | 2.1961 | 9.44 | 2.2450 | 9.89 | 2.2915 |
| 8.55 | 2.1459 | 9.00 | 2.1972 | 9.45 | 2.2460 | 9.90 | 2.2925 |
| 8.56 | 2.1471 | 9.01 | 2.1983 | 9.46 | 2.2471 | 9.91 | 2.2935 |
| 8.57 | 2.1483 | 9.02 | 2.1994 | 9.47 | 2.2481 | 9.92 | 2.2946 |
| 8.58 | 2.1494 | 9.03 | 2.2006 | 9.48 | 2.2492 | 9.93 | 2.2956 |
| 8.59 | 2.1506 | 9.04 | 2.2017 | 9.49 | 2.2502 | 9.94 | 2.2966 |
| 8.60 | 2.1518 | 9.05 | 2.2028 | 9.50 | 2.2513 | 9.95 | 2.2976 |
| 8.61 | 2.1529 | 9.06 | 2.2039 | 9.51 | 2.2523 | 9.96 | 2.2986 |
| 8.62 | 2.1541 | 9.07 | 2.2050 | 9.52 | 2.2534 | 9.97 | 2.2996 |
| 8.63 | 2.1552 | 9.08 | 2.2061 | 9.53 | 2.2544 | 9.98 | 2.3006 |
| 8.64 | 2.1564 | 9.09 | 2.2072 | 9.54 | 2.2555 | 9.99 | 2.3016 |
| 8.65 | 2.1576 | 9.10 | 2.2083 | 9.55 | 2.2565 | 10.00 | 2.3026 |

Hyperbolic Logarithms of Numbers from 1 to 30—(*Cont.*)

| Number | Logarithm | Number | Logarithm | Number | Logarithm | Number | Logarithm |
|---|---|---|---|---|---|---|---|
| 10.25 | 2.3279 | 12.75 | 2.5455 | 15.5 | 2.7408 | 21.0 | 3.0445 |
| 10.50 | 2.3513 | 13.00 | 2.5649 | 16.0 | 2.7726 | 22.0 | 3.0911 |
| 10.75 | 2.3749 | 13.25 | 2.5840 | 16.5 | 2.8034 | 23.0 | 3.1355 |
| 11.00 | 2.3979 | 13.50 | 2.6027 | 17.0 | 2.8332 | 24.0 | 3.1781 |
| 11.25 | 2.4201 | 13.75 | 2.6211 | 17.5 | 2.8621 | 25.0 | 3.2189 |
| 11.50 | 2.4430 | 14.00 | 2.6391 | 18.0 | 2.8904 | 26.0 | 3.2581 |
| 11.75 | 2.4636 | 14.25 | 2.6567 | 18.5 | 2.9173 | 27.0 | 3.2958 |
| 12.00 | 2.4849 | 14.50 | 2.6740 | 19.0 | 2.9444 | 28.0 | 3.3322 |
| 12.25 | 2.5052 | 14.75 | 2.6913 | 19.5 | 2.9703 | 29.0 | 3.3673 |
| 12.50 | 2.5262 | 15.00 | 2.7081 | 20.0 | 2.9957 | 30.0 | 3.4012 |

## SECTION 4

# PROPERTIES OF SOME MATERIALS USED IN ENGINEERING

This section does not include all of the materials used in engineering; the list relates more particularly to the common metals, and of these iron and steel have been given the larger space because of their commercial importance and extended use in machine construction and structural work. Brief consideration has been given to the non-ferrous metals and the non-metallic substances which so profoundly influence the chemical and physical properties of iron during its conversion into steel. There are commercially available many materials used in engineering which are not included in this section: a considerable number of these are given in the United States Navy Specifications included in this volume; these specifications are so complete in themselves that repetition in this section would serve no useful purpose. The subjects have been arranged in alphabetical order, to which have been added certain artificial products, as well as definitions of some of the terms used in metallurgy.

**Acetylene,** $C_2H_2$. Specific gravity 0.92. At 0° C., 32° F., acetylene weighs 0.0807 pound per cubic foot, or 1 pound = 12.392 cubic feet. At 62° F. it weighs 0.070 pound per cubic foot, or 1 pound = 14.286 cubic feet. Acetylene is a hydrocarbon gas, which may be formed by passing an electric current between carbon poles in an atmosphere of hydrogen, the carbon and the hydrogen combining directly. The resultant gas is colorless, has a peculiar pungent odor, and burns with a luminous, smoky flame.

Commercial acetylene is not thus produced, but by bringing water into contact with calcium carbide. The gas thus given off while not strictly pure is nearly so; the pungent odor of crude acetylene made from calcium carbide is greatly modified by purification, its pungency disappears and the purified gas has a not unpleasant ethereal odor. An analysis of acetylene from calcium carbide by Vivian B. Lewes was found to consist of 92.3% carbon and 7.7% hydrogen.

Weight of acetylene from calcium carbide. Under standard British conditions (60° F. and 760 mm. barometric pressure) 1,000 cubic feet of acetylene weigh 69.18 pounds dry and 68.83 pounds saturated. Unless the gas has been passed through a chemical drier, it is always saturated with aqueous vapor, the amount of water present being governed by the temperature and pressure. Under average conditions 1,000 cubic feet of acetylene weigh 69 pounds, or one cubic foot weighs 0.069 pounds, or 1 pound = 14.493 cubic feet.

Acetylene has the highest candle-power and heat unit content of any gas yet produced. A few of the hydrocarbons in the acetylene series have been grouped by J. M. Morehead, progressively from methane to acetylene, thus:

| | |
|---|---|
| 1. Methane $CH_4$ 5.2 candle power | 4. Ethylene $C_2H_4$ 70.0 candle power |
| 2. Ethane $C_2H_6$ 37.7 candle power | 5. Butylene $C_5H_8$ 123.0 candle power |
| 3. Propane $C_3H_8$ 56.7 candle power | 6. Acetylene $C_2H_2$ 240.0 candle power |

It is impossible to go further than acetylene in this direction, as the two elements in the combination do not unite.

**Acid.**—A salt of hydrogen in which the hydrogen can be replaced by a metal, or can, with a basic metallic oxide, form a salt of that metal and water:—Differently expressed by Hiorns, an acid is a salt whose base is water, a definition which becomes apparent when separating the acid from a salt in which the acid appears to be left without having any substitute for the removed alkali; such is not the case, however, because water is found to enter into union instead of the base. Every true acid contains hydrogen, and if the hydrogen is displaced by a metal, salts are formed directly; therefore, an acid is a salt whose metal is hydrogen.

All acids have one essential property, viz., that of combining chemically with an alkali or base, forming a new compound that has neither acid nor alkaline character. The new bodies formed in this way are *salts*. Every acid is therefore capable of pro-

ducing as many salts as there are basic substances to be neutralized; and this salt-forming power is the best definition of an acid substance. The secondary properties common to most acids are: solubility in water; a sour taste; the power of turning vegetable blues, litmus, for example, to red; the power of destroying more or less completely the characteristic properties of alkalies, at the same time losing their own distinguishing characters, forming salts. All these secondary properties are variable; and if we attempted to base a definition on any one of them, many important acids would be excluded. Take the case of a body like silica, so widely diffused in nature:—Siliceous sand or flint is insoluble in water; devoid of taste; and does not act on vegetable coloring matters; yet this substance is a true acid, because, when heated along with soda or lime, it forms a new body commonly called glass, which is chemically a salt of silicic acid. Other acids having properties similar to silica might easily be mistaken for neutral bodies if the salt-forming power was overlooked.

**Acidic.**—This term is applied to the acid element, as silicon, in certain salts; it is opposed to *basic*. The term is also used to denote a large amount of the acid elements: as, for example, the acidic feldspars, which contain 60% or more of silica.

**Acidific.**—That which produces acidity or an acid:—said of the elements (oxygen, sulphur, etc.) which in a ternary compound are considered as uniting the basic and acidic elements. Thus in calcium silicate, calcium is called the *basic*, silicon the *acidic*, and oxygen the *acidific* element.

The oxides of metals are usually basic in character, but this property is only relative, as an oxide which is basic in one compound may become acid when allied with a stronger base. Oxides, as the compounds of oxygen with other elements are termed, may be roughly divided into two groups:

1. Those which have an acid character, chiefly oxides of the non-metals and are often termed acids, such as carbonic acid $CO_2$ and silica $SiO_2$.

2. Those of a basic character, chiefly oxides of the metals, which are termed bases. These two classes are opposite in character, and, when united in equivalent proportions, generally neutralize each other, forming what are termed *neutral* bodies, which do not possess the characteristic properties of either kind. Thus silica $SiO_2$ will neutralize oxide of iron FeO, forming a silicate, which is neither acid nor basic. If any compound contain an excess of acid or base, it is classified either as an acid or as a basic substance according to the kind which predominates, thus, $3FeO.SiO_2$ is a basic silicate, and $FeO.SiO_2$ an acid silicate, because in the former there is more FeO than is required to neutralize the acid $SiO_2$, and in the latter less than is necessary for the purpose.

Iron forms three oxides: ferric oxide, $Fe_2O_3$, ferroso-ferric oxide, $Fe_3O_4$, and ferrous oxide, FeO. The lower oxides are converted into the higher by oxidation and the higher into the lower by reduction. The higher oxides of several of the metals are acidic. This is markedly so in the case of chromium and manganese.

**Acid oxides** of the same element are distinguished by the termination of *-ous* and *-ic* as sulphurous and sulphuric—the latter containing the most oxygen; they are also called anhydrides. They unite with water and form acids having the same terminations. By replacement of the hydrogen by a metal they form salts distinguished by the terminations *-ite* and *-ate* respectively. These acids are called oxygen acids; formerly it was thought that all acids contained oxygen, this element being regarded as the acidifying principle. But many acids are formed by direct union of hydrogen with an element, as hydrochloric acid (HCl), hydrosulphuric acid ($H_2S$), or with an organic radical, as hydrocyanic acid, H(CN).

Acids are said to be monobasic, dibasic, tribasic, etc., according as one, two, or three atoms of hydrogen can be replaced by a metal.

**Air** consists essentially of the two elements nitrogen and oxygen in the proportion of 79 volumes of nitrogen to 21 volumes of oxygen, or, by weight, of 77% of nitrogen and 23% of oxygen. Besides nitrogen and oxygen, the air contains a little ozone, carbon dioxide, a trace of ammonia, and a variable proportion of aqueous vapor depending on the temperature, direction of the wind, etc. The oxygen and nitrogen are in a state of mechanical mixture, and not in chemical combination, their ratio is always uniform. The ozone occurs in country air only; the carbon dioxide is much influenced

by local causes, therefore varies considerably. The ammonia in the atmosphere is in too small a quantity for direct estimation.

The atmospheric pressure at the level of the sea is 14.7 pounds per square inch; one pound of dry air occupies a space 12.387 cubic feet at 32° F., equivalent to 0.0807 pound per cubic foot. At 62° F. there are 13.141 cubic feet per pound, equivalent to 0.0761 pound per cubic foot. At the surface of the sea the mean pressure of the atmosphere is sufficient to balance a column of mercury 29.92 inches (760 millimeters), or one of water 33.90 feet in height. Air at 62° F. = 30 inches of mercury.

The density of air at 62° F. fixed as 1.000 is made the standard with which the specific gravity of other gases is compared. If water be made unity, then the specific gravity of dry air is 0.001293. At 62° F. air is 819.4 times lighter than water.

The specific heat of air at constant pressure is 0.2375, water = 1.0000. The specific heat of air at constant volume = 0.1689. The ratio of the specific heat of air, or constant pressure divided by constant volume = 1.406.

Air being an elastic gas may be compressed and when compressed heat is evolved; when compressed air is used as power it is expanded and cold is produced. In a perfect machine the heat of compression and the cold of expansion would equal each other, but there are no perfect machines and losses inevitably occur. The compression of air may be carried out in two ways: *isothermally*, with constant temperature through some refrigerating device; *adiabatically*, in which the temperature is allowed to increase according to the pressure, the containing vessel being protected to keep in the accumulated heat. In engineering practice the production of compressed air is by machines, which combine both isothermic and adiabatic compression.

**Alcohol.**—Ethyl alcohol, $C_2H_6O_3$, when pure is a colorless, limpid liquid of pungent and agreeable taste and odor; its specific gravity, at 15.5° C. (60° F.) is 0.7938, and that of its vapor referred to air 1.613. Specific heat at 0° C., 0.5475. It is very inflammable, burning with a pale bluish flame, free from smoke. It boils at 78.4° C. (173° F.) when in the anhydrous state; in a diluted state, the boiling point is higher, being progressively raised by each addition of water. It mixes with water in all proportions with evolution of heat and contraction of volume; it readily absorbs moisture from the air, and from substances immersed in it. The solvent powers of alcohol are very extensive. It dissolves many organic substances, as the vegeto-alkalies, resins, essential oils, and various other bodies, hence its extended use in the arts.

Alcohol is obtained by the fermentation of sugars, when a solution of them is mixed with yeast. It is extracted from spirituous liquors by distillation, but in commerce the strongest is known as spirit of wine, and contains about 90% alcohol. The remaining 10% of water must be removed by some chemical agent that will combine with water and retain it at the boiling point of the spirit, and be without any specific action on the alcohol. The most efficient dehydrating agent is caustic lime or caustic baryta. Lime is generally used in making the absolute alcohol of commerce.

**Industrial alcohol** is the name given to an alcohol denatured in order that it may not be used for other than technical purposes. The formula for completely denaturing alcohol given by the regulations of the U. S. Internal Revenue is as follows: To 100 parts of ethyl alcohol add 10 parts of approved methyl alcohol and one-half of 1 part of approved benzine.

When used for lighting, it must be burned in a state of gas and the heat produced by the combustion utilized to produce incandescence in the ordinary mantle which surrounds the common gas flame for the same purpose. Alcohol motors, especially in the smaller sizes, will become quite common as soon as the technique of construction is practically complete and the price of alcohol is sufficiently low. As compared with gasolene, which becomes volatile at 98.5° F., alcohol requires from 158° to 176° F. to volatilize rapidly enough for motor purposes.

Tests made by R. M. Strong and Lanson Stone, on the comparative values of gasolene and denatured alcohol in internal-combustion engines, for the Bureau of Mines, showed that for tests on the gasolene engine: Specific gravity of the gasolene at 60° F. was 0.7122. Heating value: High, 20,581; low, 19,292 B.t.u. per pound. Per cent alcohol by weight 94.3. The engine used was rated at 10 HP. In round numbers the compression of gasolene in the cylinder was 72 pounds per square inch;

the brake horsepower 11.41; gasolene consumed per brake horsepower-hour was 1 pound; B.t.u. per brake horsepower-hour was 12.540; compression in alcohol cylinder 126 pounds per square inch, the brake horsepower 12.98; alcohol consumed per brake horsepower-hour was 1.005 pounds; B.t.u. per brake horsepower-hour was 10620. As a net result of this series of tests no definite conclusions were reached, but the alcohol engine was throughout found to be relatively less efficient than the gasolene engine.

**Alkali.**—This term is used to denote a strong base, which is capable of neutralizing acids, so that the salts formed are either completely neutral, or, if the acid is weak, give alkaline reactions. Alkalies turn reddened litmus blue, they have a soapy taste, act on the skin and form soaps with fats. The volatile alkalies are ammonia and the *amines* of organic chemistry, which have a strong alkaline reaction like ammonia and unite with acids to form salts.

The alkaline metals are potassium, sodium, caesium, rubidium, and lithium. They are soft, easily fusible, volatile at high temperatures, combine very energetically with oxygen; decompose water at all temperatures; and form strongly basic oxides, which are very soluble in water, yielding powerfully caustic and alkaline hydrates, from which the water can not be expelled by heat.

Alkaline earths are oxides of the metals barium, strontium, and calcium. They are less soluble in water than the true alkalies, but exhibiting similar taste, causticity, and action on vegetable colors.

**Allotropy.**—The capacity of an element to exhibit different properties, although its conditions are identical as regards chemical composition, physical state, and external influences, such as pressure, temperature, etc., Roberts-Austen describes as a change of internal energy occurring in an element at a critical temperature, unaccompanied by change of state. The allotropic theory as related to iron assumes three critical points, or evolutions of heat, as shown in cooling a piece of very mild steel from a temperature of 1000° C.

1. A slight evolution of heat at about 890° C., termed $Ar_3$.
2. A disengagement of heat at about 765° C., termed $Ar_2$.
3. Another point at about 690° C., small in very mild steel and highly accentuated in steels high in carbon, termed $Ar_1$.

The presence of dissolved cementite lowers the temperature at which these changes occur, in precisely the same manner as the presence of dissolved carbon in cast iron lowers the temperature of its freezing point. Iron in the *gamma* form will dissolve about 1% of carbon as cementite, at about 890° C., but *beta* iron will scarcely dissolve any carbon, so that the beta iron, being practically free from combined iron, undergoes the change to *alpha* iron at the normal temperature of 765° C. Meanwhile as the iron falls out, the residual solution becomes richer in cementite until at 690° C. it is saturated, forming an eutectic solid solution, and the cementite and iron (in the alpha form) separate out, side by side, to form the well-known *pearlite*. The evolution of heat at 690° C. marks the point known as $Ar_1$.

**Alloy.**—A mixture of two or more metals united by melting the more refractory metal and dissolving the less refractory metal in it; forming a new composite metal with characteristics of its own differing from either of its constituents. Gun metal composed of copper, tin, and zinc may be used as an illustration; copper is a red metal with chemical and physical properties all its own, it melts at 1083° C.; tin is a white metal of less specific gravity and a much lower melting point, viz., 232° C.; zinc is wholly different from either, its melting point is 419° C.; when these are fused into an alloy: 88% Cu, 10% Sn, 2% Zn, the melting point is 995° C. The tensile strength of copper is about 27,800 pounds per square inch; that of tin 12,760 pounds; that of zinc 5,400 pounds. The tensile strength of the alloy is about 32,000 pounds per square inch. By changing the above proportions of tin and zinc to copper, a bronze is obtained of different qualities, differing in color, hardness, and tensile strength, thus: 60% Cu, 15% Sn, 25% Zn, has a tensile strength of about 18,000 pounds per square inch. A few per cent of tin causes copper to be hard and more tenacious. A brass casting of 60% Cu, 40% Zn, will have a tensile strength of about 46,000 pounds per square inch. The addition of 2.5% lead will improve the working qualities, while a large addition, say 10% lead, will make it brittle.

Metallic elements do not at first sight appear to combine in certain ratios and form definite compounds; it is probable, however, that some metals do unite in definite proportions; by the general law of affinity, all metals ought to combine chemically. As a general rule metals which form alkalies have a particular tendency to unite with those which form acids. Potassium, which is one of the alkali metals, combines readily with antimony, which is both an acid-forming and a base-forming element; it also combines with arsenic, especially when present as arsenic oxide or arsenic acid, the latter being a very powerful acid.

When two metals are near in the series of affinities for oxygen, they do not combine very readily; and they may often be separated by crystallization only, when their degree of fusibility is sufficiently distinct. This happens when both metals absorb the same, or nearly the same, quantity of oxygen in forming oxide. All chemical combinations liberate heat; silver and platinum, when melted together, produce a high temperature, so do zinc and copper. In most cases, we obtain a mere mechanical mixture of metals in an alloy; this is always characterized by forming distinct crystals with one metal, between which the other metal is visible. When an alloy is formed which contains equivalents, no such disconnected crystals are observed. The number of definite compounds is very large, and in all cases a metal is never obtained pure whenever another is present. In cooling a melted alloy, that composition which is most refractory crystallizes first; and that which is most fluid is compelled to occupy the spaces between the crystals of the most refractory. Thus, copper and tin are very fusible; but in cooling, copper-tin crystallizes first and the tin-copper last; which latter occupies the spaces between the first.

Alloys are more fusible than the mean temperature at which the metals melt singly. This is an important law and affords, when properly applied, the most valuable results. When an alloy of two metals is fusible at a lower heat than the mean of the two, a composition of three metals is still more fusible than their various degrees of melting indicate. If an alloy is more fusible than a single metal, it follows that, when one or the other constituent is removed, the fusibility of the alloy is impaired.

When metals are melted together and form an alloy there is produced a remarkable change in their specific gravity; which is sometimes greater and at other times less than the mean. A condensation of volume occurs and the specific gravity of the compound is greater than the mean of the constituents in the case of copper with tin, zinc, or antimony; lead with zinc, bismuth, or antimony. An expansion takes place when iron is combined with antimony, bismuth, or tin; also copper and lead, tin and zinc, lead or antimony, zinc and antimony.

The hardness of alloys is generally greater than may be inferred from the nature of the constituents; still there are exceptions to this rule. Copper and tin, two very soft metals, may be made extremely hard by melting them together in certain proportions. Hard zinc and copper make soft brass. Antimony causes all metals to become hard.

The ductility of alloys is in some cases greater than the elements indicate, that of lead and zinc being very tenacious. On the contrary, some alloys are more brittle than the original metals; thus lead and antimony are very brittle. Two or more brittle metals melted together are always brittle. Any alloy, when slowly heated and gradually cooled, annealed, is softer than an alloy which is suddenly chilled. Heat here, as everywhere, weakens affinity.

In the case of iron when combined with carbon to form steel, we have a metal combined with a non-metal; this also is called an alloy. Metals dissolved in mercury are called amalgams.

**Aluminium,** Al.—Atomic weight, 27. Specific gravity: Molten metal, 2.54; cast metal, 2.66. This latter may be increased by hammering or rolling. Weight per cubic foot, 165 pounds = 0.096 pound per cubic inch. Melting point, 659° C., 1,218° F., depending on its purity. Small amounts of silicon and iron, which are always present, have a considerable effect on its behavior, both physically and in contact with reagents. Volatilization of aluminium does not take place at temperatures commonly had in carbon fired furnaces, but it should not on this account be long subjected to temperatures much above its melting point, as the molten metal readily absorbs gases which affect

unfavorably the quality of the castings. Specific heat at 0° C. = 0.2098, at 100° = 0.2236, at 300° C. = 0.2434, at 500° C. = 0.2739, at 650° C. = 0.3200. Latent heat of fusion, 51.30 B.t.u. per pound. Coefficient of linear expansion, 0.00002312 at 40° C., 104° F. At 600° C., 1,112° F., the coefficient is 0.00003150. Heat conductivity, 35, silver = 100. In Smithsonian Physical Tables the conductivity is given as 0.3435 at 0° C. and 0.3619 at 100° C. The electrical conductivity is 57, silver = 100. Taking copper as 100, aluminium with purity 98.5% = 55; at 99% purity = 59; at 99.5% purity = 61; at 100% purity = 66. Its elastic modulus (*i.e.*, load in kilograms per square millimeter, divided by its alteration in length) is 7,462 as compared with 11,350 for copper, and the torsion moduli of these metals are 3,350 and 4,450 respectively.

Color: Pure aluminium is nearly as white as silver, but the commercial metal has a bluish white cast intermediate between the colors of tin and zinc.

The hardness of aluminium varies with its purity, the purest metal being the softest. In relative hardness, the diamond = 1,000.0; aluminium is 272.8, that is, softer than gold and harder than tin. The ordinary commercial aluminium is about as hard as copper, which, on the same scale, is 451.8. This increase in hardness is due to the fact that aluminium commonly contains small amounts of some other metals. Aluminium hardens considerably when it is worked; mechanical processes such as pressing, forging, rolling, etc., will harden the metal; castings not subject to mechanical treatment, as above, should contain some alloying metal if hardness is particularly desired.

In malleability, aluminium ranks next after gold, but its malleability is impaired by the presence of silicon and iron. Aluminium of over 99% purity is rolled into sheets of only 0.0005 to 0.0007 of an inch in thickness, and such sheets are hammered into leaf nearly as thin as gold leaf. Aluminium leaf is largely used in decorative work, and has almost entirely superseded the use of silver leaf because of the softness of tone and non-tarnishing qualities when in contact with gases which blacken silver. Aluminium bronze paint is the leaf ground into powder and mixed with oil and drier.

The ductility of aluminium is next after that of copper; it has been drawn into a very fine wire, but, as in the case of malleability, the ductility is impaired by the presence of silicon and iron. Aluminium wire has a tensile strength of 30,000 to 45,000 pounds per square inch. It has been largely used for overhead electrical transmission and it possesses many advantages for such purposes owing to its lightness; for the same diameter, the weight of aluminium wire is only about one-third that of copper, while its electrical conductivity is 60% that of copper.

The tensile strength of aluminium castings is from 12,000 to 15,000 pounds per square inch, but this varies with the "temper" of the metal. Sheet aluminium varies between 22,000 to 38,000 pounds per square inch, depending on the amount of hammering or other work done upon the ingot before the final rolling. The elastic limit approximates one-half the tensile strength. The physical properties of bars are about the same as given for sheets. Wire has a tensile strength of 30,000 to 45,000 pounds per square inch. The above figures are for nearly pure metal; a higher tensile strength can be had if suitably alloyed. When compared with equal weights, aluminium bars are as strong as steel bars of 80,000 pounds per square inch.

The compressive strength of aluminium in short columns, length equaling twice the diameter, is not very much different from its tensile strength when the metal is nearly pure, but in the case of high or hard alloys it may be twice as much. The elastic limit is somewhat less than half the compressive strength when the metal is nearly pure, but is gradually lowered with increasing hardness of the alloy until it is barely more than one-quarter the compressive strength for the hardest alloys.

Under transverse tests nearly pure aluminium is not very rigid; the metal will bend nearly double before breaking.

Corrosion: The resistance of aluminium to oxidation is one of its most marked qualities. Pure aluminium is not acted upon by air, wet or dry, and not at all by sulphur fumes; it does not tarnish from the influence of illuminating gas or of the weather. If silicon is present to any great extent, say 2 to 3%, aluminium will not so well withstand atmospheric corrosion. Boiling water or steam does not affect it. Organic secretions have less effect upon it than is the case with silver; it is, therefore, used for dental plates, surgical instruments, suture wires, and in places subject to carbolic acid

and other antiseptic solutions. Salt water has little effect upon it, and it withstands the action of sea water better than iron, steel, or copper. It is not acted upon by carbonic acid, or carbonic oxide, or sulphuretted hydrogen, at any temperature below 600° F.

Solubility: Hydrochloric acid, weak or concentrated, is the true solvent for aluminium. Concentrated sulphuric acid dissolves the metal on heating, with evolution of sulphurous acid gas; dilute sulphuric acid acts only slowly on the metal. The presence of any chloride in the solution, however, allows the metal to be rapidly decomposed. Nitric acid, either concentrated or dilute, has very little action on the metal. Sulphur has no action on it at a temperature less than red heat. Solutions of caustic alkalies, chlorine, bromine, iodine, and fluorine rapidly corrode aluminium. Aqua ammonia acts slowly on aluminium; ammonia gas does not appear to act upon the metal.

Hydrogen is absorbed by aluminium to the extent of about equal volumes, and this is expelled on heating.

Oxygen does not attack aluminium in bulk at ordinary temperatures, but if the aluminium is finely divided it undergoes considerable oxidation at 400° C., 752° F., or even, though less rapidly, at lower temperatures. This affinity which finely divided aluminium possesses for oxygen has been made use of by Goldschmidt in the application of "thermit" as a means of reducing oxides, having used it successfully in the production of iron, manganese, chromium, nickel, cobalt, titanium, boron, molybdenum, tungsten, vanadium. and other metals.

The sonorous qualities of pure aluminium are very pronounced, but the tone seems to be improved by alloying with a few per cent of silver or German silver.

The non-magnetic quality of aluminium is useful in electrical work where a magnetic material would be useless.

The electrical conductivity of pure aluminium is about 62 in the Matthiessen Standard Scale. As in the case with other metals of good electrical conductivity, the conducting power of aluminium is greatly decreased by the presence of alloying metals.

Impurities commonly found in aluminium are silicon and iron. Silicon exists in two forms, one seemingly combined with the metal, much as combined carbon exists in pig iron, and the other as an allotropic graphitic modification. Pure aluminium is soft and not so strong as the alloyed metal; it is only where extreme malleability, ductility, sonorousness, and non-corrodibility are required that the purest metal should be used.

The alloying metals added to produce hardness, rigidity, and strength, constituents that will not detract from the lightness of the metal and also will not affect its non-corrosive qualities are, commonly, copper, nickel, and zinc.

The purity of commercial aluminium varies from about 94 to 99.75%, the balance being made up of impurities, such as silicon, iron, copper, etc. The approximate composition of No. 1 grade of aluminium by the Aluminium Company of America is 99.55% aluminium, 0.15% iron, 0.30% silicon.

The fracture of pure aluminium is slightly fibrous, uneven, rough and very close. Metal 96 to 97% pure is feebly crystalline, breaks short with a tolerably level surface. When less than 95% pure the fracture is crystalline. The presence of a small percentage of silicon will change the fibrous to crystalline structure, and thus unfit it for stamping or working cold.

Alloys: Aluminium added to certain metals, such as copper or iron, even in small quantities, has a profound effect in modifying their properties; so also the addition of small quantities of metals, such as iron, manganese, or the metalloid silicon, effects considerable change in the properties of aluminium. The alloys of aluminium may be classed as bronzes, casting alloys, and rolling alloys, according to their properties.

**Amalgams.**—Alloys of mercury with other metals are termed *amalgams*, mercury dissolves the metals gold, silver, tin, lead, etc., but not iron or platinum. In some cases the union takes place with considerable evolution of heat and large modification of the mean properties of the components. Thus, for instance, sodium when rubbed up with mercury unites with it with deflagration and formation of an alloy which, if it contains more than 2% sodium, is hard and brittle, although sodium is as soft as wax and mercury a liquid.

Liquid amalgams of gold and silver are employed in gilding and silvering objects

of copper, bronze, etc. The amalgam is spread out on the surface of the object by means of a brush, and the mercury is then driven off by the application of heat, when a polishable, firmly adhering film of the dissolved metal remains. Gold forms with mercury a compound $AuHg_3$, and the amalgam remaining after squeezing the excess of mercury through chamois leather contains 33% gold. Silver and mercury form a definite compound $Ag_2Hg_2$; by squeezing the excess of mercury through chamois leather an amalgam of fairly uniform composition is obtained $Ag_2Hg_2 + 4.6\%$ mercury.

Tin amalgams are made by adding mercury to molten tin. The amalgam of equal parts of mercury and tin is a brittle solid; but with more mercury a plastic mass is obtained, which becomes hard in the course of a few days. The amalgams are used in a plastic condition, and harden with little or no expansion. The amalgam of tin is used in silvering looking-glasses.

Copper amalgam containing 25 to 33% of the solid metal, when worked in a mortar at 100° C., becomes highly plastic, but on standing in the cold for 10 or 12 hours becomes hard and crystalline. It may be softened again by immersing it in boiling water or by simply pounding it; and it is capable of being hammered, rolled, and polished. It hardens without expanding or contracting. It is used as a cement for metals and is also used for cementing china and porcelain.

The fluidity of an amalgam depends on there being an excess of mercury above that necessary to form a definite compound.

**Ammonia**, $NH_3$.—Specific gravity of ammonia gas at 0° C., and 76 centimeters (atmospheric) pressure relative to air at 0° C. and the same pressure, is 0.597, equalling 0.048 pound per cubic foot. The mean specific heat of ammonia gas for temperatures 23° to 216° C., the pressure constant, is 0.5228. The latent heat of vaporization of ammonia when temperature of vaporization is 16° C. is 297.4 calories per kilogram, or therms per gram (Regnault). The critical temperature of ammonia gas according to Dewar is 130° C., under pressure of 115.0 atmospheres, 1,691 pounds per square inch. Nitrogen and hydrogen have not by any commerical process been combined so as to yield ammonia directly; it has been done in small quantity in an experimental way, but the practical difficulties are very great.

One of the chief sources of ammonia at the present time is ammoniacal liquor of gas works obtained through the distillation of bituminous coal. The gaseous materials which pass over from the retort are partly uncondensable and truly gaseous; these pass into the gas holder for service; but there are other gaseous materials passing over which are condensable, and during the process of washing the gas these are condensed into a mixed tarry and watery liquid. After this gas liquor has settled, the water portion containing ammonia is drawn off. By one method hydrochloric acid is added to the liquor, forming a compound of ammonia and hydrochloric acid called chloride of ammonium. Pure ammonia can be obtained from this impure chloride of ammonium by mixing it with its own weight of slaked lime in a retort and applying a gentle heat; the ammonia gas passes over and is received in a vessel containing water, from which the gas may be liberated by a further application of heat.

Ammonia gas is colorless, has a strong pungent odor, and possesses marked alkaline properties, turning reddened litmus to blue, and combining readily with acids, neutralizing them completely. It does not support combustion or respiration. It does not burn in the air, but does burn in oxygen with a pale yellowish flame.

Ammonia as generally obtained, even in the gaseous condition, is in combination with the vapor of water, the gas containing 1 part nitrogen, 4 of hydrogen, and 1 of oxygen as $NH_4O$. Dry ammonia gas can be had by passing this mixed ammonia vapor over fused chloride of calcium, when the water is abstracted and true gaseous ammonia is left, having the composition 1 nitrogen and 3 hydrogen, $NH_3$.

Ammonia gas can be liquefied under pressure and cold, yielding a colorless, clear, mobile liquid, with the characteristics of ammonia much intensified. When the pressure is removed from the liquefied ammonia it passes back to the gaseous form and in so doing it absorbs heat, and this is the property taken advantage of for the artificial preparation of ice.

The solubility of ammonia gas in water is very great, 1 volume of water at ordinary temperature dissolving about 670 volumes of ammoniacal gas, increasing in bulk, and

forming a liquid which is lighter than water, its density being 0.875, water = 1.000. At 0° C. (32° F.) water will take up about 1,000 volumes of gas. This liquid solution of ammonia is transparent, colorless, and strongly alkaline; it has the power to neutralize acids and form salts. This solution is commonly known as spirits of hartshorn. If this liquid be heated to the boiling point nearly all of the gas may be expelled from it.

**Antimony,** Sb.—Atomic weight, 120. Specific gravity, 6.71. Melting point, 630° C. (1,166° F.). Specific heat, 50.03. Antimony is a brilliant silver-gray metal, having a foliated texture and a strong tendency to assume a crystalline structure. It is brittle, and can be reduced to powder with ease. It is not oxidized by the air at common temperatures; when heated to redness it takes fire, burning with a brilliant white flame. It is dissolved by hydrochloric acid. Nitric acid oxidizes it to antimonic acid. Antimony is valuable for the alloys it yields with other metals. Britannia metal is an alloy largely used, containing usually about 81 parts of tin, 16 of antimony, 2 of copper, and 1 of zinc. Babbitt's anti-friction metal for the bearings of machinery is composed of 83.3 parts of tin, 8.3 parts of copper, and 8.3 parts of antimony. Antimony combines with lead or tin, separately or in combination, and such alloys are much used in place of gun metal for lining bearings and for bushings of both light and heavy machinery.

**Arsenic,** As.—Atomic weight, 74.9. Specific gravity, 5.73 in the solid state. Its vapor density, compared with that of hydrogen, is 150, which is twice its atomic weight. Melting point, 850° C. (1,562° F.). Specific heat, 0.081. Arsenic is sometimes found native; it occurs in considerable quantity as a constituent of many minerals, combined with metals, sulphur, and oxygen. The largest proportion is derived from the roasting of natural arsenides of iron, nickel, and cobalt. Arsenic has a steel-gray color and high metallic luster; it is crystalline and very brittle; it tarnishes in the air, but it may be preserved unchanged in pure water. When heated it volatilizes without fusion, and if air be present, oxidizes to arsenious oxide. At red heat it burns with a bluish flame, and the vapor given off has the odor of garlic. Arsenic combines with metal in the same manner as sulphur and phosphorus; it resembles the latter in many respects, and it is often regarded as a metalloid. It is used for mixing with lead in the manufacture of small shot, the alloy dropping in rounder forms than pure lead. An alloy of copper and arsenic produces a brittle gray metal of a brilliant silvery hue.

**Asbestos.**—A variety of the mineral hornblende. It contains a considerable percentage of magnesia in its composition, with an almost equal percentage of silica.

Amianthus is one variety of asbestos characterized by long flexible fibers of flaxen aspect; these fibers are so easily separated and so soft that they may easily be spun into yarn and woven into a cloth. The fibers of common asbestos are shorter and much less flexible. It is also heavier than the amianthus variety. It has a dull green color, sometimes pearly luster, and unctuous to the touch.

The composition of asbestos is practically the same wherever found, as illustrated in the following comparative analyses of Italian and Canadian samples, given by J. T. Donald:

| | | Italian | Broughton, Canada |
|---|---|---|---|
| Silica | $SiO_2$ | 40.30% | 40.57% |
| Magnesia | $MgO$ | 43.37 | 41.50 |
| Ferrous oxide | $FeO$ | .87 | 2.81 |
| Alumina | $Al_2O_3$ | 2.27 | .90 |
| Water | $H_2O$ | 13.72 | 13.55 |
| | | 100.53% | 99.33 |

Chemical analysis throws light upon an important point in connection with asbestos, *i.e.*, the cause of the harshness of the fiber of some varieties. From the

analyses just given it may be seen that asbestos is principally a hydrous silicate of magnesia, *i.e.*, silicate of magnesia combined with water. When harsh fiber is analyzed it is found to contain less water than the soft fiber. In fiber of very fine quality from Black Lake, analysis showed 14.38% of water, while a harsh-fibered sample gave only 11.70%. It is well known that if soft fiber be heated to a temperature that will drive off a portion of the combined water, there results a substance so brittle that it may be crumbled between thumb and finger. There is evidently some connection between the consistency of the fiber and the amount of water in its composition. It is probable that the harsh fiber was, as originally deposited, soft and flexible, and has been rendered harsh by having a portion of its water driven off by heat, either produced by movement of the associated rocks or resulting from the injection of molten matter through volcanic action.

**Austenite.**—This term is applied by Osmond to a constituent of high carbon steels which is developed by very sudden quenching from a high temperature. It is softer and less magnetic than martensite, with which it is generally associated. It is found in steels containing more than 1.2% carbon which have been quenched from a temperature above 1,000° C. in water cooled to 0° C., or, better, in a freezing mixture. Owing to the fact that it is only stable at high temperatures, it has been suggested that it may be a solution of elementary carbon in iron. It is not of frequent occurrence in steel.

**Barium,** Ba.—Atomic weight, 137. Specific gravity, 3.78. Weight per cubic foot, 236 pounds = 0.13 pound per cubic inch. Melting point, 850° C., 1,560° F., and commences to volatilize at 950° C., 1,742° F. Specific heat, 0.037. When pure, barium is a silver-white metal. It is slightly harder than lead. Barium is never found native, but occurs principally as the sulphate $BaSO_4$, barytes or heavy-spar, and is generally found associated with metallic ores containing sulphur. It also occurs in nature as witherite, $BaCO_3$, and in certain varieties of the ores of manganese; also in certain silicates. Guntz states that molten barium attacked all the metals he tried, iron and nickel being the most resistant. Barium decomposes water and alcohol in the cold, yielding in the latter case barium ethoxide. Barium oxidizes rapidly in the air, yielding principally the monoxide BaO. Barium peroxide, or dioxide $BaO_2$, is formed when baryta is heated to a dull red in a stream of oxygen or of air freed from carbonic acid; the barium peroxide is a gray, impalpable powder, slightly more fusible than the monoxide. Goldschmidt has used the peroxide in his "thermit" process to start the reaction in a mixture of finely granulated aluminium with a solid oxide. A fuse of aluminium and barium peroxide is used which is ignited by burning a piece of magnesium.

**Base.**—A metallic oxide which is alkaline, or capable of forming with an acid a salt, water being also formed, the metal replacing the hydrogen in the acid.

**Basic.**—Having the base in excess; having the base atomically greater than that of the acid or that of the related neutral salt; a direct union of a basic oxide with an acid oxide.

**Bessemer Process.**—A process invented by Henry Bessemer (1856) by which steel is made directly from a special pig iron low in both sulphur and phosphorus, first melting the pig iron in a cupola and then pouring a certain quantity of this molten metal into a vessel called a converter; after which atmospheric air at a pressure of 20 to 25 pounds per square inch is blown into and through this molten iron in numerous fine jets through tuyeres placed at the bottom of the converter; the tuyere openings communicate with an air supply chamber directly underneath.

The process is essentially a chemical one in which the atmospheric oxygen is the active element, the numerous openings in the tuyeres combined with the high air pressure break up the air into a mass of bubbles in the molten iron, thus offering a large surface of contact for chemical reaction, the effect of which is to oxidize the carbon, manganese, silicon, and other oxidizable constituents originally contained in the pig iron, leaving only a decarburized iron with its unoxidizable constituents in the converter; this metal is then recarburized by dissolving in it as much of a special iron known as spiegeleisen or ferromanganese as will supply the needed carbon and manganese to give the steel the desired chemical and physical properties. Two methods are employed in making Bessemer steel: The acid process, in which the converter is lined with

acid material, the product being Acid Bessemer Steel; in the other process the lining of the converter is of basic material, and this product is called Basic Bessemer Steel.

The lining in an acid Bessemer converter is made of the most refractory acid materials procurable; in England, ganister is used; this is a siliceous rock in which the silica is cemented together by a species of clay; a typical composition is: 92.0% silica, 3.5% alumina, 2.7% ferric oxide, together with small amounts of lime and magnesia. Ganister is also used in this country. Mica-schist forms a good lining, this mineral is an aggregate of quartz and mica in widely varying proportions, the mica occurs in thin plates or layers between the quartz layers. Sometimes the quartz may retain a granular character like that of quartz-rock. When mica-schist is placed in a converter it should be so laid as to present its laminar section to the action of the metal, the joints between the blocks should be completely filled with a refractory fire clay. A good refractory lining may be made by the use of old silica fire bricks and remnants, after crushing the bricks to the equivalent of one-half inch cubes; mixing these with a finely crushed quartz, or with a refractory fire sand, cementing all by a good quality of fire clay sufficiently moistened to make a stiff mixture that will stand driving into place.

Acid Bessemer pig is a gray iron which is specially made for conversion into steel by the acid process. The composition is by no means uniform, the following composition is to be regarded as approximate only:

| | | |
|---|---|---|
| Silicon, | not over | 2.00% |
| Carbon, | total | 3.50 |
| Manganese, | not over | 1.00 |
| Phosphorus, | less than | 0.10 |
| Sulphur, | less than | 0.10 |

In regard to the phosphorus and sulphur neither of these is reduced during the blow because the slag is too acid, they therefore remain in solution in the iron to be corrected after the blow. Phosphorus is not removed in the acid Bessemer process because ferrous phosphide is not decomposed during the blow and the phosphorus in the manganese phosphide passes over to the iron. It is for this reason a special pig iron is made for the acid Bessemer process.

Carbon in the molten iron is oxidized by the air blown up through it in the converter. The rate at which carbon is eliminated in the converter depends mainly upon the percentage of silicon in the pig iron and the initial temperature. Hoffman states that with high silicon (2 to 3%) pig iron, and a low initial temperature, at first only silicon will burn, and when the iron is heated to a certain point (assisted by the oxidation of manganese), carbon begins to burn to a carbonic oxide; the English method. With low silicon (0.6 to 1.3%) pig iron, and a low initial temperature, silicon will be almost completely eliminated before the carbon begins to be much oxidized. This means quick blowing, and at short intervals; the American method.

Silicon is oxidized upon forcing of air into the molten metal, its oxidation is very rapid in the earlier parts of the blow, and unless the percentage of silicon be very high or the temperature of the blow too high, the removal of the silicon is practically complete. Silicon is best removed at a moderate temperature. No fuel is required during this process of conversion because the heat generated by the oxidation of silicon accompanied by that of the carbon is such that the iron is not only kept in a molten condition, but increases in temperature as well; a temperature of 1,640° C. (2,984° F.) has been noted by Le Chatelier, which is 120° C. (248° F.) above the melting point of iron.

Manganese contained in the Bessemer pig oxidizes readily in the converter during the blow; if it be present in quantity such as obtains in Sweden, for example, where it may reach 2.0% or even more, the manganese may oxidize before there is enough silica formed to produce a slag with the oxide. In such a case the blow is not continued until all the carbon is burned off, but the blast is stopped when the metal contains the desired amount of carbon as determined by spectrum analysis of the flame, as well as by the color of the slag. A blow thus controlled, according to Hiorns, results in from 0.1 to 0.3% manganese remaining in the iron. American Bessemer pig, containing less

manganese than the above, does not require a shortening of the blow; by its presence it assists as a heat producer, shields the iron from oxidation, combines with the silicon and passes off with the slag.

The object of the blow is to supply air for the elimination of the foreign constituents in the molten pig iron, but the elimination is not wholly complete; when the flame drops at the mouth of the converter, out of a probable 3.50% in the pig, there yet remains about 0.10% carbon in the iron; so also, out of a probable 1.00 to 1.50% silicon there may be as much as 0.10% still present in the metal. The temperature of the molten pig iron in the converter must be such as to keep both the metal and the slag in a fluid state; the heat generated by the oxidation of silicon, in the acid process, is sufficient for this purpose. If the silicon be too high the blow will be too hot, and if the metal be too hot the carbon will oxidize more rapidly than the silicon, an excess of silicon occurs, and the quality of the steel will be low; to prevent this, it is the common practice, when the blow seems to be too hot, to add cold scrap to the metal in the converter, or steam is admitted into the air-supply chamber, whence it passes with the air into the molten metal and effects through its dissociation a reduction in temperature; when the temperature of the metal has been sufficiently reduced the steam is shut off; if, however, through low silicon, the temperature be too low, the general effect is unsatisfactory; Howe considers that as far as convenience of blowing is concerned, 1.25% silicon is the best proportion.

The effect of the blow is to oxidize everything oxidizable in the converter: Iron is oxidized and becomes FeO, this oxide will combine with manganese Mn, forming a new compound, $Fe + MnO$. Iron, and silicon, Si, will combine thus, $2\,FeO + Si = 2\,Fe + SiO_2$. Iron and carbon will combine thus, $FeO + C = Fe + CO$. These compounds react upon each other during the blow until chemical equilibrium is established; if this occurs before the end of the blow the carbon will be practically eliminated, as will the manganese also; the silicon becomes silica associated with manganese oxide and ferrous oxide; these with alumina and other impurities constitute the slag. As the sulphur and phosphorus are not oxidized in the acid Bessemer process they remain in the converter in practically the same proportion as in the pig; some of the sulphur passes into the slag, but none of the phosphorus.

Length of blow: The Bessemer process is a very rapid one: in an 8-ton converter the time interval between charging the converter with molten iron from the cupola and the blast turned on, until the appearance of the carbon flame from the mouth of the converter, is about 3 minutes, the full carbon flame developing within a minute. About 5 minutes thereafter the converter is turned down, the blast is shut off, and melted spiegeleisen is added, or, in the case of ferro-manganese being used, it is shovelled into the stream of metal pouring from the converter into the ladle. After the pouring, it requires less than a minute to empty the converter of slag and place it in position to receive another charge of metal from the cupola. The total time from start to finish is about 20 minutes, half of which is taken up by the blow.

The record of a 15-ton converter at the Carnegie works, as summarized, is as follows: Charge 33,000 pounds of direct metal and 2,500 pounds of scrap. Spiegeleisen added, 3,000 pounds. Time between heats, less than 18 minutes; time of blowing, about 14 minutes. Slag formed, about 12% on the weight of pig iron. The loss of iron, about 10%.

After the blow, when all the oxidizable constituents in the iron have been removed, there remains in the converter a mass of molten iron low in carbon with oxide of iron sufficiently in excess to give it properties resembling "burnt" iron; it is spongy, red-short, and non-malleable. Manganese is now added to the molten metal either in the form of spiegeleisen in the case of mild steel, or as ferro-manganese when a higher carbon and manganese content are required; this addition corrects the objectionable properties enumerated above, and converts the molten iron into a product both homogeneous and malleable, some of the sulphur may be eliminated but the phosphorus remains. Of the manganese added in the spiegeleisen, 70% enters the steel, while 30% is oxidized and enters the slag. Of the carbon added by the spiegeleisen, 80% enters the steel. Carbon is added to the molten metal in the converter through that contained in the spiegeleisen; mild steel such as used for structural purposes contains about 0.25% carbon, steel rails from 0.40 to 0.60%.

Ingot steel made by the acid Bessemer process varies somewhat in composition, partly through incomplete oxidation during the blow, and partly through lack of uniformity in composition of the spiegeleisen or ferro-manganese added after the blow. The variation may not be much, but it is enough to require analysis or physical tests before working. With the exception of the maximum limitation of 0.10% on phosphorus in acid Bessemer steel, less attention is given than formerly to the chemical properties. For ordinary structural steel, such as shapes, bars, or plates, the tensile strength is usually all that is required, it being understood that the elastic limit is one-half that amount. There are no sharp limitations as to tensile strength in this grade of steel; it may vary anywhere between 55,000 and 65,000 pounds per square inch, subject also to a cold bending test through 180° to a diameter of one thickness. Any steel that will pass such a physical test, with maximum 0.10% phosphorus, will be suitable for structural work, or any other service in which ordinary wrought iron would be used that does not require welding. The chemical problem is to produce such a steel, and when this is attained, the physical requirements are all that enter into ordinary specifications.

The loss of iron during its conversion from pig iron into steel is occasioned by the rapid oxidation of the molten iron by the passage of the numerous finely divided jets of air through it; this oxidation begins very early in the blow and continues to the end. Silicon is a source of heat and especially useful in the early part of the blow, but silicon unites with iron, and leaves the converter as a silicate of iron in the slag; the greater the percentage of silicon thus converted the greater the loss of iron. The total loss of iron by the acid Bessemer process is about 10%, but this is by no means uniform.

Slag:—Manganese combines with oxygen in four well-defined oxides, of which the monoxide $MnO$ is the only one to be here considered. This oxide is isomorphic with magnesia $MgO$; it combines with both iron and carbon, forming a double carbide. In the presence of sulphur, it decomposes the iron sulphide, forming manganese sulphide, liberating the iron; this sulphide is not as soluble in iron as iron sulphide, it therefore tends to float to the surface, and thus pass into the slag. In the first stages of the blow manganese oxide predominates largely, but as the blow goes on, the proportion of iron oxide increases rapidly. The proportion of manganese present in the slag is nearly the same in amount as that present in the molten iron from the cupola.

Silicon is always present in pig iron, chiefly as silicide of iron $FeSi$; this silicide dissolves readily in molten iron; its effect upon the carbon also present in the iron is to change it from the combined to the graphitic form, in which form it is readily oxidized.

Average composition of acid Bessemer slag at the end of the blow, before the addition of the spiegeleisen:

| | | |
|---|---|---|
| Silicon, | $SiO_2$ | 48.8% |
| Lime, | $CaO$ | 1.4 |
| Alumina, | $Al_2O_3$ | 3.1 |
| Manganese oxide, | $MnO$ | 33.8 |
| Ferrous oxide, | $FeO$ | 12.5 |

The amount of slag is approximately 12% on the weight of pig iron used.

**Basic Bessemer Process.**—When a Bessemer converter is lined with a basic material, the slag produced will have the characteristics of the lining and will also be basic; such a slag will take up elements whose oxides are of an acid character. When in contact with a basic lining, or with basic slag, the phosphorus in the molten metal is oxidized and becomes phosphoric oxide, which readily unites with bases such as lime and magnesia, passing into the slag, leaving a purer iron. This application of a basic lining such as lime and magnesian limestone in a converter was patented by Snelus in 1872. Thomas and Gilchrist later reduced the principles of the Snelus patent to practical operation in the use of a basic lining of crushed limestone and sodium silicate, as well as magnesian limestone bricks to the converter, and by the further addition of a small amount of lime, or lime mixed with "blue billy" (burnt pyrites) or some other form of iron oxide such as mill scale, to the charge, together with the continuance of the blow for some short period after the decarbonization is complete, the elimination

of phosphorus could be very largely effected, some 80 or 90% of the total phosphorus present becoming oxidized and converted into phosphates, this action chiefly taking place during the *afterblow*.

The pig iron best suited to the basic Bessemer process is a white iron which contains less silicon than gray pig iron. White irons show no trace of graphite in the fractured pig; they are also likely to be much more phosphoric than gray irons; the percentage of sulphur is commonly higher than in gray irons. The presence of much silicon operates against the success of the basic process because an extra amount of lime will be necessary to effect removal of the phosphorus from the iron; inasmuch as the oxidation of the phosphorus produces sufficient heat to keep the iron liquid, no loss of heat occurs during the blow.

The basic blow is divided into two distinct periods, the foreblow and the afterblow. The foreblow is distinguished by the same phenomena which occur in the acid blow, viz., the pale flame and sparks during the first combustion of the manganese and silicon, the white flame increasing in length as the carbon burns out and the abrupt drop of the flame when the carbon combustion of the flame is completed. A few seconds after the drop of the flame the manganese lines in the green portion of the flame spectrum disappear, and the afterblow begins. In the foreblow, carbon, silicon, manganese, and some phosphorus are oxidized; in the afterblow the remainder of the phosphorus and sometimes sulphur are oxidized.

The fundamental principle of the basic blow, according to F. E. Thompson, is to calculate the amount of air and lime required to oxidize the silicon, manganese, and phosphorus estimated or known to be contained in the iron.

Theoretically the molten iron comes to the converter at a good regular temperature, successive heats having a uniform chemical composition for certain periods. Often the iron comes irregular in both temperature and composition from heat to heat. This is especially true as regards iron from a melting cupola carrying steel scrap, and applied in some measure to iron direct from the blast furnace.

Some design of mixer, however, drawing molten iron from the blast furnace offers the best means of delivering regularly hot and uniform basic iron to the converter.

Converter Metal at Conclusion of Blow Before Recarburizing—Basic Bessemer Process

(*F. E. Thompson*)

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Carbon | 0.03% | 0.04% | 0.04% | 0.04% |
| Silicon | Trace | Trace | Trace | Trace |
| Sulphur | 0.058 | 0.028 | 0.053 | 0.036 |
| Phosphorus | 0.035 | 0.030 | 0.020 | 0.025 |
| Manganese | 0.060 | 0.050 | 0.120 | 0.032 |

The only regular additions to the afterblow are scrap, lime, and recarburizers. Scrap is added, as in the acid process, to lower the bath temperature sufficiently to yield a quiet steel at the casting pit. Part of the total lime charge may be added during the afterblow, but most works now prefer to add the lime all at once before the converter is turned up for the blow. Lime may be added also during the afterblow instead of scrap, in order to cool the bath and thicken the slag. This action will increase the percentage of iron in the slag, and also increase the amount of metallic shot mechanically inclosed in the slag, leading to increased loss by conversion.

In blowing metal of normal composition the blow lasts from 12 to 18 minutes, according to the analysis of the iron and according to the blast pressure. The proportions of time to each period is about 10 minutes for the foreblow and five minutes for the afterblow. Air delivered at converter = 28 to 32 lbs. per sq. in. The quantity

of air is about 8,928 cubic feet per ton during the foreblow and 4,960 cubic feet during the afterblow.

The overblow in basic work is similar to that in acid work, in that it begins when the usual combustibles in the bath are consumed and the iron itself begins to burn. Overblowing in the basic converter in presence of excess of lime conduces to a more complete elimination of phosphorus and to a more rapid elimination of sulphur, accompanied by an increase in the amount of oxide of iron going with the slag. Overblowing without excess of lime in the slag, on the other hand, increases the phosphorus in the metal bath by rephosphorization, makes the slag thin and wild, and forces oxide of iron into the metal bath. The steel produced is brittle when cold, and shows a characteristic oxide glitter in the fracture.

It is an open question when the overblow begins. The whole matter rests upon the final phosphorus content of the steel. If we say that the steel of a completed basic blow should contain 0.08% phosphorus, then the overblow begins when the phosphorus in the metal bath has been reduced to that point. But if we say that normal basic steel should contain 0.04% phosphorus, then the overblow begins at that point. Should we place the phosphorus limit below 0.01%, most blows would have no overblow because the metal bath would probably contain that much phosphorus as long as there remained any metal in the converter.

Mr. Thompson determined the average conversion loss accompanying different values of phosphorus in the steel in order to see what value gives the most economical results consistent with good soft steel. He found that basic steel containing 0.04 to 0.06% phosphorus is most economically produced. This grade of steel is also better suited for structural work than that containing either very low phosphorus or phosphorus above 0.06%.

Temperature: There are no phenomena accompanying the basic afterblow by which the bath temperature can be judged with the extreme nicety attained in acid practice. Close observation of the brown fumes is the best temperature guide. In an exceedingly hot blow the flame will be almost entirely obscured shortly before the completion of the blow; but the hotter the blow the lower is the conversion loss, unless a large excess of lime be present. It is not the oxide of iron going up the stack during the hot blow which causes heavy conversion loss, but the oxide of iron and metallic iron going into the slag during a cold blow, which usually results either from excess of lime or overscrapping.

Very hot blows generally result from excess of combustibles in the iron. When lime is normal and not greatly in excess, very hot blows often produce phosphoric steel owing to the fact that phosphorus, toward the end of the blow, does not pass readily into the slag, at a high temperature. Lowering the temperature of the bath by scrap additions serves the double purpose of cooling off the steel and facilitating the elimination of phosphorus.

Mr. Thompson's estimate is that scrapped hot heats yield an average conversion loss of 14.83%, compared with 12.81% loss in unscrapped heats.

Basic Bessemer Slag—Average Composition of Four Heats

(*F. E. Thompson*)

| | | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Silica, | $SiO_2$ | 5.12% | 6.10% | 7.28% | 8.14% |
| Ferrous oxide, | $FeO$ | 16.85 | 15.42 | 19.89 | 19.68 |
| Manganese oxide, | $MnO$ | 3.82 | 3.89 | 4.17 | 4.00 |
| Lime, | $CaO$ | 50.04 | 48.96 | 48.46 | 47.28 |
| Phosphorus pentoxide, | $P_2O_5$ | 20.30 | 19.92 | 16.62 | 16.81 |
| Magnesia, | $MgO$ | 1.21 | 1.02 | 0.68 | 0.52 |
| Aluminium oxide, | $Al_2O_3$ | 1.40 | 2.10 | 2.40 | 2.50 |
| Sulphur, | S | 0.34 | 0.29 | 0.41 | 0.41 |
| Moisture | | 0.91 | 2.33 | 0.11 | 0.68 |

Mr. Thompson's experience with phosphoric iron (about 2.5% phosphorus) is that in normal blows the phosphorus is about one-half burned out at the conclusion of the foreblow. In very hot or long foreblow the phosphorus may be reduced much more than one-half before the afterblow begins, while in a generally cold blow the phosphorus may remain practically unchanged until the afterblow has progressed well toward the middle. The whole phosphorus reaction depends upon the melting of the lime, and when this occurs phosphorus begins to be oxidized, whether or not carbon be present in the bath.

Sulphur in the basic converter is more of a fixture than the other elements. In a normal blow, the iron of which contains about 0.10% sulphur, about 50% of the sulphur may be removed by overblowing. When the sulphur in the iron exceeds 0.10%, from 50 to 90% may be removed in the converter.

**Bismuth,** Bi.—Atomic weight, 208. Specific gravity, 9.8. Melting point, 271° C., (520° F.). Specific heat, .0303. Bismuth is a hard, brittle metal, the fracture is highly crystalline and white, with a perceptible red tinge by reflected light. Its electric conductivity, according to Matthiessen, is 1.19 at 14° C., silver being 100 at 0° C. It is the most strongly diamagnetic of all metals. It does not change in dry air, but in moist air it oxidizes superficially; when melted at a red heat it oxidizes, and the oxide, by a higher temperature, melts to a glassy substance, in which property it resembles lead, the oxide, like litharge, exerting a corrosive action upon earthen crucibles or substances containing silica at a red heat. Bismuth is but slightly acted upon by hydrochloric or sulphuric acids in the cold; but the latter dissolves it more readily when heated. The best solvent is nitric acid, which attacks it readily.

Bismuth unites readily with other metals, the alloys being remarkable for their ready fusibility and their property of expanding on solidification. Fusible alloys containing bismuth are used to some extent as safety plugs for steam boilers, as an accessory to the safety valve.

**Blister Steel** is the common name for steel made by the cementation process, from the blistered appearance of the bars when taken from the converting pot. These bars are often simply cut into pieces, piled, heated to a welding heat, and forged, when it is converted into *shear steel;* if this process is repeated it becomes *double shear steel;* but when a perfectly homogeneous product is required it is melted in crucibles, when it becomes *cast steel.*

The nature of the chemical changes taking place during cementation has been often regarded as somewhat uncertain, but is probably due to the occlusion of carbon oxide in the iron and its decomposition by the metal into carbon and an iron oxide, which is subsequently again reduced by a second portion of carbon oxide, the two changes going on simultaneously. The escaping carbon dioxide, which penetrates through the metal less readily than does carbon oxide, and hence is apt to accumulate in certain parts, is probably the cause of the blistering of the surface of the steel, especially with puddled bars containing small quantities of ferrous silicate disseminated through them; Percy has shown that fused homogeneous metal free from interspersed slag does not give rise to blisters upon cementation.

Many cyanogen compounds, especially ferrocyanide of potassium, when applied to iron in a heated state convert it exteriorly into steel, such as case hardening, and it has in consequence been supposed that nitrogeneous substances are essential to the carbonization of iron by cementation and that nitrogen is an essential constituent of steel. The evidence in behalf of this is, however, at present unsatisfactory; on the other hand, charcoal rich in alkalies, or a mixture of charcoal powder with a little lime and soda, will carbonize iron submitted to cementation more rapidly than charcoal more free from alkalies.

In order to carry out the process of cementation, the bars of iron are placed in a fire-brick box or chest several feet long, layers of charcoal and iron being alternately piled in until the chest is filled, when a luting of fire clay, or of the sandy ferruginous mud produced in grinding and polishing steel articles after manufacture termed "wheel-swarf," is applied so as to close up the upper part of the box and prevent access of air; two or more such chests are then arranged under the arched roof of a chamber erected over a fireplace in such a way that the flames of the fire pass under and lap round

the sides of the chest, and impinge upon the roof; the gases escaping through orifices in the roof into a conical chimney built over the whole. Trial bars are arranged in the mass of charcoal in such positions that they can be withdrawn from time to time, and the progress of the operation examined by fracturing the bars after cooling, and seeing when the core of the wrought iron disappears; from 7 to 10 days' heating, according to the amount of carbonization required (averaging about 1.0%), is generally allowed, with a total charge of some 10 to 20 tons of iron in the furnace. When the requisite carbonization is attained the fire is raked out and the chests are allowed to cool; the blister steel is then melted down into cast steel, or converted into shear steel by piling and forging, etc.

A slight lowering of sulphur content in the iron is said to occur during cementation; experimentally, the quantity has been about 0.007% in Swedish bar iron, but no noticeable effect is produced on the silicon, phosphorus, or manganese originally present, so far as the irregular way in which traces of cinder, always interspersed throughout the bars of wrought iron, will permit conclusions to be drawn. Analysis of Dannemora bar iron and its resultant steel by the cementation process:

| | Fe | C | Mn | Si | S | P |
|---|---|---|---|---|---|---|
| Iron | 99.471 | 0.352 | 0.075 | 0.050 | 0.027 | 0.025 |
| Steel | 98.603 | 1.250 | 0.072 | 0.035 | 0.0222 | 0.018 |

A difference of 0.007% phosphorus will be noted, but this is without significance, as the permissible quantity of phosphorus in steel of any grade, high or low, is 0.03%. Some irons contain a great deal of phosphorus; as practically none of it disappears during the process of conversion into steel, the practice is to select the purest bar irons for this purpose.

**Borax.**—A sodium salt derived from boric acid. Its chemical formula is $Na_2B_4O_7$; its specific gravity is 1.7 = 106 pounds per cubic foot. Its melting point is 561° C. When heated, borax puffs up, and at red heat it melts, forming a transparent, colorless liquid. In its molten condition it combines with and dissolves many metallic oxides; it is used in the process of soldering metals, its action consisting in rendering the surfaces to be joined metallic by dissolving the oxides. In the manufacture of alloys, to prevent oxidation as far as possible, the metals are melted in graphite crucibles and covered with a layer of charcoal or other carbonaceous material. In some cases borax is used as a covering, as it melts easily and forms a protecting layer, while at the same time it combines with any metallic oxides present and keeps the molten metal clean.

**Boron,** B.—Atomic weight, 10.9. Specific gravity, 2.68 = 167 pounds per cubic foot. Melting point, 2,200° C. (4,000° F.). This element belongs to the same family as aluminium, and in the composition of its compounds it is undoubtedly similar to aluminium; but, on the other hand, its oxide is distinctly acidic, while that of aluminium is basic. Its occurrence in nature is chiefly in the form of boric acid, or the salts of this acid, from which boron is obtained in amorphous form; it is a dull, greenish-brown powder, which burns in the air when heated, producing boric oxide. Boron is used as a deoxidizer for copper in the production of copper castings for electrical work. Unlike many other deoxidizers, boron does not alloy with copper, so that the addition of a slight excess does not impair the electrical conductivity of copper.

**Cadmium,** Cd.—Atomic weight, 112. Specific gravity, 8.6. Melting point, 321° C. (610° F.). Specific heat, 0.0548. Cadmium is a white metal with a slight bluish tinge by reflected light; it is whiter than lead or zinc, but less so than silver, has a high luster and polish, and breaks under a gradually increasing strain with the fibrous fracture characteristic of the soft, tough metals. It is somewhat harder than tin, but less so than zinc, and like tin it emits a peculiar crackling sound when bent. It is malleable and may be rolled into thin sheets. Its electric conductivity is 22.10, or somewhat lower than that of zinc. It unites readily with most of the heavy metals,

forming alloys, which with gold, copper, and platinum are brittle, while those with lead and tin are malleable and ductile. An alloy of two parts of cadmium, two of lead, and four of tin, known as Wood's fusible metal, melts at a somewhat lower point than the similar alloy where bismuth takes the place of cadmium. It forms several amalgams, among which those containing equal parts of mercury and cadmium and two of mercury to one of cadmium are remarkable for their cohesive power and malleability; whereas that containing 22% of cadmium is hard and brittle. When exposed to damp air cadmium becomes rapidly covered with a dull film of suboxide, but as with zinc the oxidation is only superficial. When heated to redness in air, it burns, forming a yellowish-brown oxide. It is soluble in sulphuric, hydrochloric, nitric, and acetic acids.

**Calcium,** Ca.—Atomic weight, 40. Specific gravity, 1.54. Melting point, 810° C. (1,490° F.). Specific heat, 0.1804. Calcium is one of the most abundant and widely diffused of the metals, though it is never found in the free state. Calcium is a light yellow metal, about as hard as gold, very ductile and may be cut, filled, or hammered out into thin plates. It tarnishes slowly in dry, more quickly in damp air; calcium decomposes the water quickly, and is still more rapidly acted upon by dilute acids. Heated on platinum foil over a spirit lamp, it burns with a bright flash; with a brilliant light also when heated in oxygen or chlorine gas.

**Calcium Carbide,** $CaC_2$, specific gravity 2.22; 138.5 pounds per cubic foot, is now made in quantity by fusing an intimate mixture of finely powdered carbon and pure lime in the electric furnace, in the proportion of about 60 parts of lime to 40 parts of carbon, by weight. The carbon may be either powdered coke, charcoal, or anthracite, but coke running low in ash is commonly used. The temperature required to fuse the mixture of powdered coke and lime into carbide is given by Lewes as 2,700° C. when made directly by arc-carbons, which is the commercial method. The chemical reaction being $CaO + C_3 = CaO_2 + CO$. Pure carbide fresh from the furnace bears a resemblance to crushed granite, it is of crystalline appearance, very dark in color and with a purple tinge. It is a safe substance to store or transport, but it must be properly packed to exclude the smallest trace of moisture. It cannot explode, take fire, or otherwise do harm.

**Carbon,** C.—Atomic weight, 12. Specific gravity: diamond, 3.50, graphite, 2.25, charcoal, 1.80. Specific heat of diamond, 0.366. Carbon is one of the most important of the chemical elements. It occurs pure in the diamond, and nearly pure as graphite; it is a constituent of all animal and vegetable tissues and of coal. The diamond is the hardest substance known, and has a relatively high specific gravity. Graphite, or plumbago, appears to consist essentially of pure carbon, although most specimens contain iron. In the electric arc carbon appears to be converted into vapor; but the temperature which is required to volatilize it is extremely high. Graphite is used for making crucibles, for lubricating machinery, and is the so-called black lead used in making pencils. In the electrotype process it is used for coating the surfaces of wood, plaster of Paris, and other non-conducting materials so as to render them conductive. The purest amorphous carbon ordinarily met with is lampblack, which is prepared by the imperfect combustion of highly carbonized bodies, such as resin. An amorphous carbon of considerable purity, known as gas-retort carbon, is obtained in the manufacture of coal gas. It is a good conductor of heat and electricity, and burns with difficulty, and is therefore employed in producing the electric light. Wood charcoal and coke are impure forms of amorphous carbon, and animal charcoal is a still more impure form. There are two direct inorganic compounds of carbon and oxygen called carbon monoxide and carbon dioxide; their composition by weight may be thus stated:

Carbon monoxide $CO$ = carbon 12 + oxygen 16 = 28.
Carbon dioxide $CO_2$ = carbon 12 + oxygen 32 = 44.

**Cementation Process.**—The conversion of wrought iron bars into steel by direct carbonization is accomplished when the bars are enveloped in powdered charcoal in a converting pot from which air is carefully excluded, heated to redness for several days, during which time the bars gradually become carbonized and converted into steel;

the deposition of the carbon commencing at the outside of the bars and gradually penetrating inward, a longer time being consequently requisite for the carbonization of thicker than of thinner bars. This process is called cementation; the powdered substance, in this case charcoal, is called the cement and the wrought iron is said to have undergone cementation.

**Cementite.**—The carbide of $Fe_3C$, so named by Howe; it was first discovered in steel made by the cementation process, and has been variously described as cement carbon, or as carbide carbon, to distinguish it from other forms of carbon found in iron and steel. According to the atomic weights of iron (56) and of carbon (12) cementite must contain $\frac{12 \times 100}{3 \times 56 + 12} = 6.67\%$ carbon.

It therefore contains 93.33% iron and 6.67% carbon, which corresponds to the chemical formula $Fe_3C$.

Cementite is an intensely hard carbon, being, in fact, the hardest of all the constituents occurring in iron and steel; it will scratch glass and feldspar, but not quartz. It has therefore a hardness of about 6.5.

Cementite may also contain small amounts of silicon and sulphur dissolved in it possibly as silicide and sulphide of iron respectively. When containing much manganese it has been called manganiferous cementite. Manganese and sulphur apparently increase the stability of cementite while silicon decreases it.

Steel containing more than 0.9% carbon, if cooled slowly from a high temperature, will have its carbon all in the form of cementite; the percentage of carbon multiplied by 15 will give the percentage of cementite, and the difference between this and 100 will be the percentage of ferrite. The ferrite will all be present as pearlite; the percentage of cementite in the pearlite will be the percentage of ferrite divided by 6.4, and the pearlite will of course be the sum of the two. The metal will thus consist of pearlite and free or excess cementite. Free cementite does not occur in normal mild steel, and is practically absent from highly hardened steels.

**Chromium,** Cr.—Atomic weight, 52. Specific gravity, 6.7. Melting point, 1510° C. (2,750° F.). Specific heat, 0.120. Chromium is one of the metallic chemical elements, so called in allusion to the fine color of its compound. It does not occur in the free state or very abundantly in nature. It is a constituent of the minerals chrome ironstone, chrome ocher, chrome garnet, etc. It is the cause of the color of green serpentine, pyrope, and the emerald. The alloy termed *chromeisen,* containing about three parts by weight of chromium to one of iron, is hard enough to serve for cutting glass. An extremely soft steel can be made by employing it instead of *spiegeleisen* in Siemens' steel process.

**Cobalt,** Co.—Atomic weight, 59. Specific gravity, 8.79 at 17° C. for unannealed metal; 8.81 at 14.5° C. after annealing. Melting point, 1,490° C. (2,714° F.). Specific heat, 0.103. It has a tensile strength of about 34,100 pounds per square inch, and a compressive strength of about 122,000 pounds per square inch as cast; after annealing the tensile strength was 36,980 pounds, the compressive strength was 117,200 pounds per square inch respectively. Cast cobalt containing 0.06% carbon has a tensile strength of 61,000 pounds and a compressive strength above 175,000 per square inch respectively. The reduction of area and elongation are low for pure cobalt, but rise to 20% in the case of commercial cobalt (96.5 to 99.6 Co) containing carbon and other impurities.

Pure cobalt is a white metal, resembling nickel in appearance, but when electro deposited and polished it has a slightly bluish cast. In hardness, by Brinnell test, it was about 124 for specimen cast in an iron mold. Under similar conditions cast nickel showed 83 and cast iron about 102. It is unchanged in the air, but feebly attacked by dilute hydrochloric and sulphuric acids. It combines most readily with arsenic or antimony, forming the highly crystalline compound known by the general name *speiss,* which can scarcely be considered an alloy. With gold and silver it forms brittle compounds, with mercury a silver-white magnetic amalgam. With copper and zinc the alloy is white, resembling the corresponding compound of the same metal with nickel and manganese; with tin it forms a somewhat ductile alloy of a violet color.

**Copper,** Cu.—Atomic weight, 63.6. Specific gravity, 8.93. Melting point, 1,083° C. (1,981.5° F.). Specific heat, 0.093. Copper is a metal of a peculiar red color; it takes a brilliant polish, is in a high degree malleable and ductile, and in tenacity it only falls short of iron. Copper castings have an ultimate tensile strength of about 25,000 pounds with an elastic limit of 6,000 pounds. Its ultimate strength under compression is about 40,000 pounds and the ultimate shearing strength is 30,000 pounds. The modulus of elasticity of annealed copper averages 10,000,000 pounds. Copper plates, rods, and bolts have an ultimate tensile strength of about 33,000 pounds with an elastic limit of about 10,000 pounds. In electric conductivity it is equal to silver. Copper undergoes no change in dry air; exposed to a moist atmosphere, it becomes covered with a strongly adherent green crust, consisting in a great measure of carbonate. Heated to redness in the air, it is quickly oxidized, becoming covered with a black scale. Dilute sulphuric and hydrochloric acid scarcely act upon copper; boiling oil of vitriol attacks it; nitric acid, even dilute, dissolves it readily. Copper unites with facility with almost all other metals; indeed, it is much more important and valuable as a constituent element in numerous alloys than it is as a pure metal. The principal alloys in which it forms a leading ingredient are brass, bronze, German silver, nickel, silver, etc.

**Crucible Steel.**—This method of steel making consists in charging a crucible with small pieces of wrought iron or of mild steel, with ferro-manganese and the addition of such other substances as will give the final product the desired chemical and physical properties; these are packed in powdered charcoal; the covered and luted crucible is placed in a suitable furnace; when the steel is melted it is poured into an ingot to be hammered, rolled, or otherwise prepared for future use. Metals melted in a crucible undergo little or no change except that incident to the chemical changes in the mixture. Wrought iron readily absorbs carbon, and mild steel takes up additional carbon from the incandescent powdered charcoal in which it is embedded; one effect of the ferro-manganese in the mixture is its union with oxygen and the formation of oxides of both iron and manganese. The addition of alloy metals such as chromium, nickel, aluminium, vanadium, is through the ferro compounds of the metals; they may be included in the crucible charge or added in metallic form, as would probably be the case with nickel, after the melting and before the pouring. The material of which the crucible is composed is not without its influence on the chemical changes which occur within it at high temperatures. In regard to the charge: the wrought iron or mild steel may be covered with rust and, perhaps, a certain amount of free moisture; gases such as oxygen, hydrogen, carbonic oxide, are known to be readily absorbed by iron, and these influence somewhat the chemical changes which take place in the crucible during the process of melting.

Crucible steel is practically restricted in its manufacture to tool steels, and most of these are alloy steels. A crucible carbon steel, 0.60% carbon; 0.52% manganese; 0.16% silicon; 0.03% sulphur; 0.03% phosphorus; when tested had a tensile strength of about 100,000 pounds per square inch, with elongation of 12% in 2 inches, and 30% reduction of area. Increasing the carbon only in this steel had the effect of increasing the tensile strength, but the percentages of elongation and reduction of area were both lowered.

A carbon steel by the American Vanadium Co. containing 0.969% carbon; 0.448% manganese; 0.139% silicon; when heat treated yielded the following:

| | | |
|---|---|---|
| Treatment: | Tensile strength | 155,000 pounds per square inch |
| 850° −600° C. | Elastic limit | 101,000 pounds per square inch |
| Oil tempered. | Elongation in 2 inches | 8.0% |
| | Reduction of area | 10.5% |

**Ferrite** is a microscopical constituent of iron and steel; it consists of practically pure iron, or iron free from carbon; it would be the chief constituent of wrought iron and mild steel if they could be made wholly free from carbon, which is not the case; it is found in low-carbon or mild steels as made for structural work; it does not occur

in hard steels. This is the "free iron" described by Sorby in his microscopical researches on the structure of iron and steel.

**Gold**, Au.—Atomic weight, 197. Specific gravity, 19.3. Melting point, 1,063° C. (1,945.5° F.). Specific heat, 0.0316. Gold is the only metal of a yellow color. It is nearly as soft as lead. When pure, gold is the most malleable of all metals. It is extremely ductile and may be drawn into very fine wire. The electric conductivity is 73.99 at 15.1° C., pure silver being 100. (Matthiessen.) The specific resistance of the metal in electromagnetic measure, according to the C. G. S. system, is 2,154. Its conductivity for heat is 53.2, silver being 100. Its coefficient of expansion for each degree between 0° C. and 100° C. is 0.000014661. The specific magnetism of the metal is 3.47. Finely divided gold dissolves when heated with strong sulphuric acid and a little nitric acid. It is also attacked when strong sulphuric acid is submitted to electrolysis with a gold positive pole. The most important alloys are those with silver and copper. The density of the alloys of gold and silver is greater than that calculated from the density of the constituent metals; these alloys are harder, more fusible, and more sonorous than pure gold. Certain metals, even when present in small quantities, render gold brittle and unfit for rolling; these metals are bismuth, lead, antimony, arsenic, and zinc.

**Graphite.**—A crystallized form of carbon, known also as *plumbago*, and popularly known as black lead. It occurs usually in compact and crystalline masses, but occasionally in six-sided tabular crystals which cleave into flexible laminæ parallel to the basal plane, iron black or steel gray in color, with metallic luster.

Graphite is a kind of mineral carbon, its specific gravity is 2.2. It can be converted into carbon dioxide by the action of nitric acid. As the carbon is usually associated with more or less iron, the older mineralogists described the mineral as a carburet of iron—but Vanuxen demonstrated that the iron is present as ferric oxide and not as a carbide. The ash left on the combustion of graphite usually contains, in addition to the ferric oxide, silica, alumina, and lime.

Exposed on platinum foil to the flame of the blow-pipe, graphite burns, but often with more difficulty than diamond. When heated with a mixture of potassium dichromate and sulphuric acid, it disappears.

In order to obtain perfectly pure graphite, the mineral is first ground and washed to remove earthy matter, and then treated, according to Brodie's method, with potassium chlorate and sulphuric acid; on subjecting the resulting product to a red heat, pure carbon is obtained in a remarkably fine state of division.

The following analyses are selected from a large number by C. Méne (Compt. rend. 64.1091):

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Carbon | 91.55 | 81.08 | 79.40 | 78.48 |
| Volatile matters | 1.10 | 7.30 | 5.10 | 1.82 |
| Ash | 7.35 | 11.62 | 15.50 | 19.70 |
| | 100.00 | 100.00 | 100.00 | 100.00 |

1. Very fine Cumberland graphite, specific gravity, 2.345.
2. Graphite from Passau, Bavaria, specific gravity, 2.303.
3. Crystallized graphite, from Ceylon, specific gravity, 2.350.
4. Graphite from Buckingham, Canada, specific gravity, 2.286.

Excellent graphite is found in Siberia, in the Tunkinsk Mountains, Irkutsk. This deposit occurs in gneiss, associated with diorite. It has been largely worked to supply Faber's pencil factory.

The best quality of graphite found in large quantities is that from Ceylon.

In the United States, graphite is widely diffused, but rarely in sufficient quantity

to be worked. The principal locality is Ticonderoga, N. Y., where the Dixon Crucible Co. have worked a schist containing about 10% graphite.

In consequence of its refractory character, graphite is largely used in the manufacture of crucibles, retorts, tuyeres, and other objects required to withstand high temperatures.

**Harvey Steel.**—The conversion of mild or low carbon steel into a higher grade having the characteristic qualities of crucible steel is possible by Harvey's method, the essential conditions being the subjection of the ingot or the body of steel to the presence of carbon, the absence of oxygen, and a high temperature, the latter varied according to the degree of hardness which the product is required to be capable of taking in the subsequent process of tempering; the higher the temperature during the conversion the higher will be the temper which the resultant steel is rendered capable of taking.

The ingots or other bodies of steel which are to be treated are embedded, preferably in finely powdered, hard-wood charcoal, contained in crucibles, boxes, or receptacles made of refractory material, and provided with covers to prevent the charcoal from being consumed. No special kind of furnace is required, but in practice a furnace of the regenerative type may be preferred. The shape and dimensions of the furnace chamber will be governed by the shapes and sizes of the ingots or other bodies of steel to be treated. For example, ingots, say, $2 \times 3 \times 18$ inches long may be treated in receptacles which will serve to contain 6 ingots separated from each other and from the walls of the receptacle by a thickness of one inch of powdered charcoal, the same thickness from the bottom, and a layer of 3 inches of powdered charcoal at the top. The boxes or other receptacles for the charcoal may be heated by direct contact with a body of incandescent fuel, in which they are embedded; or they may be deposited in a heating-chamber and be heated by contact with or radiation from the flames conducted through it. The time required for the heating operation will depend upon the dimensions of the bodies of steel under treatment; the object to be accomplished is the uniform heating throughout of the steel under treatment. For large masses of steel the heating operation will have to be conducted more slowly that the interior of the mass may be raised to the required temperature without melting the crucible or box in which it is packed. Mild steel thus embedded in powdered charcoal may be raised slightly above its melting point without being melted; when the desired temperature has been reached, the crucible or other receptacle containing the steel is allowed to cool off either in, or after removal from, the furnace. By this treatment a steel is produced which may be welded or tempered; its tensile strength is increased, and it has acquired the characteristics of a crucible steel of higher grade.

If the steel under treatment is to be made capable of taking a temper of a high degree of hardness, its temperature will be raised to about (1,650° C.) 3,000° F., and allowed to cool off to a temperature of, say, (94° to 149° C.) 200° to 300° F., before being removed from the powdered charcoal in which it has been embedded; the steel will on removal be found very soft, will exhibit a clean surface of dull gray or zinc color, and will be capable of taking a temper so high that tools made from it and hardened will cut chilled iron. By lowering the limit of temperature to about (820° C.) 1,500° F. the steel under treatment, when cooled, will exhibit a surface of dark-purple color, but will be capable of taking a low temper. Between these two temperatures all the characteristic temper-colors may be had together with the characteristic properties in the steel corresponding to the same shades of color in steels produced by the crucible process. The time required will depend upon the size and number of pieces to be treated; a single ingot, say, $2 \times 3 \times 18$ inches long, deposited in powdered charcoal in a crucible, say, 5 in. diam. $\times$ 24 in. long, can be successfully treated by keeping such a crucible embedded in a free burning coke fire in four to six hours. A larger ingot or a number of ingots contained in a larger crucible will require, say, 12 to 20 hours.

Armor plates require to be homogeneous in large masses, sufficiently tough as not to crack or break under impact of projectiles, yet soft enough to be worked with steel tools. By the Harvey process the face is *cemented, i.e.*, animal or wood charcoal is placed next the face of the plate (two plates being usually dealt with together, face to face), and the whole is covered in with bricks and run into a gas furnace, where it remains

two or three weeks, seven days or so being allowed for cooling. In this way the proportion of carbon on the face is increased, and the front is then capable of being hardened. The plate is first cemented as above, and then bent to the required shape and all necessary holes made in the surface. It is then heated and the face douched with cold water, which makes the front of the plate exceedingly hard. The object attained is a steel plate, without welds, having such a proportion of carbon in the surface that water cooling would produce a very hard face. As the thickness of the hard steel is practically constant for all thicknesses of plate, it follows that thin plates obtain relatively higher values of the figure of merit than thicker plates. That is, a 12 in. plate is not twice as good as a 6 in. plate.

Krupp armor plates, when first introduced, had a much higher tensile strength before treatment than had the earlier Harvey plates; the Krupp steel in addition to the usual small proportion of carbon contained, also, nickel, chromium, and manganese. Plates 3 inches and below were not cemented; after completion of the machine work they were simply heated and water-cooled. Plates thicker than 3 inches underwent cementation as by the Harvey process, but in the final face hardening the plate was not heated bodily as in the Harvey process, but the heat was graduated from the face to the back. After heating the face was cooled by placing under the cold water douche.

**Hydrogen,** H.—Atomic weight, 1.000. Specific gravity, 0.069, air = 1.000. Weight per cubic foot, 0.0056 pound, cubic feet per pound, 177.94. It is the lightest substance known. Specific heat at constant pressure, 3.406; at constant volume, 2.412; the specific heat rises with rise of temperature. Coefficient of thermal expansion at constant pressure, 0.366; at constant volume, 0.367. Specific inductive capacity, 1.0013, vacuum at 5 mm. pressure, 1.0015, when air = 1.0000. Specific inductive capacity, 0.9998. Heat of combination at constant pressure, 62,000 B.t.u.; an average of seven tests gave 34,417 cals. = 61,950 B.t.u. The critical temperature as determined by Olszewski is − 220° C. under a pressure of 20 atmospheres.

Hydrogen is colorless, tasteless, and inodorous when pure. It is only slightly soluble in water; 100 volumes of water take up 1.93 volumes of hydrogen. It is inflammable and burns, when kindled, with a pale, yellowish flame, evolving much heat, but very little light. Water is the only product of combustion when hydrogen is burnt in the air or in oxygen, the formula being $H_2O$; if we regard the atomic weight of oxygen as 16 and that of hydrogen as 1, the total weight is 18, so that hydrogen forms one-ninth the weight of water. The volume of water thus formed is so very small as compared with that of the two gases as to appear almost negligible; yet this decrease in volume truly represents the total volume of the gases, oxygen and hydrogen, which combined to form it.

The diffusive power of hydrogen is very great. Suppose a vessel to be divided into two portions by a diaphragm or partition of porous earthenware and each half filled, one with oxygen, the other with hydrogen; diffusion will at once commence through the pores of the dividing diaphragm, and will continue until an equilibrium is established. The rate of penetration is not the same for both gases; four cubic inches of hydrogen will pass into the oxygen side, while one cubic inch of oxygen passes into the hydrogen side. The atomic weights of the two gases are to each other as 16 to 1; the rate of diffusion is inversely proportional to the square roots of these numbers, or as 4 to 1; thus the diffusive power of hydrogen is four times that of oxygen.

The coefficient of diffusion for hydrogen into another gas or vapor is thus presented in the Smithsonian Physical Tables, on the authority of Obermayer. The temperature is 0° C. or 32° F. in all cases. Air, 0.6340; carbon dioxide, 0.5384; carbon monoxide, 0.6488; ethane, 0.4593; ethylene, 0.4863; methane, 0.6254; nitrous oxide, 0.5347; oxygen, 0.6788. According to Loschmidt, the coefficient of oxygen diffusing into hydrogen at 0° C. is 0.7217.

**Ingot Iron** is of molten origin; it is, in fact, a nearly carbonless steel; a good illustration is that by the American Rolling Mill Co., which is marketing under the trade name "Armco Ingot Iron" a product averaging the following composition: 0.011% carbon; 0.002% silicon; 0.019% manganese; 0.025% copper; 0.020% sulphur; 0.003% phosphorus. The tensile strength is from 38,000 to 44,000 pounds per square inch,

with elastic limit of about one-half the tensile strength. It is claimed for this product that it will resist corrosion better than any other grade of iron or steel. By reason of its low tensile strength it does not enter into structural work in competition with mild, low-carbon, or soft steels, which have a tensile strength of 55,000 to 65,000 pounds per square inch. Its manufacture is confined principally to sheets.

**Ingot Steel** is of molten origin; it may be made of the crucible, Bessemer, or open hearth processes, but not by puddling, or any cementation process. It is immaterial whether it will harden or not; the name indicates its molten origin without reference to its carbon content. Commonly, however, it applies to Bessemer or open hearth ingots intended for structural shapes, bars, plates, etc., in which the tensile strength will vary from 55,000 to 65,000 pounds per square inch, and for forgings from 60,000 to 70,000 pounds. High tensile steel such as open hearth carbon, nickel, or silicon steel may have a tensile strength of 80,000 pounds per square inch, or even higher in the case of vanadium, or other alloy steels.

**Iridium,** Ir.—Atomic Weight, 193. Specific gravity, 22.42. Melting point, 2,300° C. (4,170° F.). Specific heat, 0.0323. Iridium is a white brittle metal, fusible with great difficulty before the oxy-hydrogen blow-pipe. It has acquired importance from its employment in alloy with platinum in the construction of the international standards of length and weight. Iridium is almost indestructible, and has extreme rigidity, especially in the tube form; its coefficient of elasticity is very great; and a most beautifully polished surface can be obtained upon it. An iridio-platinum alloy containing about 20% of iridium has also a very high coefficient of elasticity, while its malleability and ductility are almost without limit.

**Iron,** Fe.—Atomic weight, 56. Specific gravity, pure, 7.8. Gray cast, average, 7.08; white cast, average, 7.66; wrought, average, 7.85. Melting point, 1,520° C. (2,768° F.). Specific heat, 0.116. Heat conductivity, 16. Electrical conductivity, 17. In magnetic characters it is superior to all other substances. Wrought iron has a tensile strength of 48,000 min. to 53,000 max. pounds per square inch, with elastic limit in no case less than one-half the tensile strength.

Pure metallic iron is rarely found in nature; nearly all specimens examined have been meteoric iron containing about 63% of metallic iron, always associated with nickel and small quantities of cobalt, phosphorus, sulphur, etc. The irons of commerce are reduced from ores in which the iron occurs chiefly as an oxide. The principal oxides of iron are ferrous oxide, FeO, ferric oxide, $Fe_2O_3$, and the magnetic or black oxide, $Fe_3O_4$. The ferrous oxide is a very powerful base, neutralizing acids, and isomorphous with magnesia, zinc oxide, etc.; it is very unstable, readily passing into the sesquioxide in the presence of oxygen. Ferric oxide is a feeble base isomorphous with alumina, it occurs native in iron ores, especially hematite. The magnetic or black oxide of iron is well known as the product of the oxidation of iron at high temperatures in the air or in watery vapor. The magnetic iron ore is known as magnetite, which, when pure, contains nearly 75% iron. Spathic iron ore is a carbonate of iron, $FeCO_3$, which, when pure, contains nearly 50% iron.

Commercial irons are extracted from ores and marketed in the form of pig iron, which consists of iron in combination with graphitic and combined carbon, silicon, sulphur, phosphorus, and manganese.

**Lead,** Pb.—Atomic weight, 207. Specific gravity: cast, 11.25 = 702 pounds per cubic foot = 0.406 pound per cubic inch; sheet or rolled lead, 11.42 = 713 pounds per cubic foot = 0.412 pound per cubic inch. The heaviest of the common metals. Melting point, 327° C. (621° F.). Specific heat, 0.0311. Lead boils at a white heat, 1,500° C. to 1,600° C. (2,732° to 2,912° F.), but it cannot be distilled. It is, however, sensibly volatile at much lower temperatures, and there is always loss when the metal is melted. Latent heat of fusion, 9.86. Coefficient of linear expansion, 0.0000292. Heat conductivity, 8.5; silver = 100.0. Electrical conductivity, 7.2; silver = 100.0. Properties of commercial lead, probably slightly alloyed; tensile strength, cast 1,920 pounds per square inch; rolled or sheet lead 2,000 pounds per square inch. Crushing weight, cast lead, 6,950 pounds per square inch.

Lead, when pure, is a feebly lustrous bluish-white metal, very soft, plastic, and almost entirely devoid of elasticity. In the air, at ordinary temperature, it is quickly

tarnished in consequence of the formation of a suboxide of the composition $Pb_2O$, but the thin, dark film thus formed is very slow in increasing.

Pure water acts upon lead when free oxygen, air for example, has access to it, and some of the lead dissolves, with formation of hydrated oxide, which is appreciably soluble in water, forming an alkaline liquid. When carbonic acid is present, the dissolved oxide is precipitated as basic carbonate, fresh, hydrated oxide is formed, and the corrosion of lead progresses. All soluble lead compounds are strong cumulative poisons, hence the danger involved in using lead-lined cisterns for the storage of *pure* water for culinary purposes. The word pure is emphasized because the presence in water of even small proportions of bicarbonate or sulphate of lime prevents its action on lead. Natural waters are more or less impure, that is, they contain something in solution. In contact with the earth, earthy substances are dissolved; for example, water which flows over limestone dissolves some of this and becomes *hard*. Among the substances met with in solution in natural waters are carbonic acid, sodium carbonate, sodium sulphate, sodium chloride, magnesium sulphate, carbonate of iron, and sulphuretted hydrogen. Waters which contain considerable quantities of sulphuric acid in the form of sulphates have a corroding action on lead; but the product of corrosion in this case is a practically insoluble compound, lead sulphate, which forms a coating on the surface of the metal and effectually prevents further corrosion, either by sulphates or by the water itself. The use of lead pipe in domestic water supply is almost universal; inasmuch as natural waters are never absolutely pure, the inside of the pipe is quickly coated with insoluble compounds, therefore the water flowing through the pipes does not come in contact with the lead and its use is generally considered harmless.

**Liquation.**—The separation of metals differing considerably in fusibility by subjecting them, when contained in an alloy or mixture, to a degree of heat sufficient to melt the most fusible only, which then flows away, or liquates, from the unmelted mass. A homogeneous liquid alloy, when solidified suddenly, yields an equally homogeneous solid. But it may not be so when it is allowed to freeze gradually. If, in this case, we allow the process to go a certain way, and then pour off the still liquid portion, the frozen part generally presents itself in the shape of more or less distinct crystals; whether this happens or not, the rule is that its composition differs from that of the mother liquor, and consequently from that of the original alloy. This phenomena of liquation is occasionally utilized in metallurgy for the approximate separation of metals from one another; but in the manipulation of alloys made to be used as such it may prove inconvenient.

The existence of crystallized alloys, as observed in the phenomenon of liquation, strongly suggests the idea that alloys generally are mixtures, not of their elementary components, but of chemical compounds of these elements with one another, associated possibly with uncombined remnants of these.

**Lithium, Li.**—Atomic weight, 7. Specific gravity, 0.54; the lightest of solid and liquid bodies. Melting point, 186° C. (367° F.). It is volatile at a high temperature, burning with a white flame. It manifests but little tendency to combine with hydrogen. Specific heat, 0.941. Electrical conductivity, 16; silver = 100.0. It attracts oxygen with avidity on exposure to air. Only one oxide of lithium has been obtained, $Li_2O$.

Lithium is one of the metals of the alkalies, of which sodium and potassium are also in the same grouping. It is a white metal having the luster of silver. It is a soft metal, softer than lead. In many of its properties it is more closely allied to magnesium and calcium than to sodium. Lithium salts communicate a beautiful red color to flame.

**Magnesia,** MgO, is an oxide of magnesium, it is a product of the combustion of magnesium in air or oxygen. It is also formed when the carbonate or nitrate is heated in the air. As thus obtained, it is a white amorphous powder, but may be obtained crystallized in cubes and octahedra by heating the amorphous form in a current of hydrogen chloride.

Calcined magnesia is a fine bulky powder, specific gravity, 3.07 to 3.20. The specific gravity is increased to 3.61 by heating in a pottery furnace. It is fusible only at the temperature of the oxy-hydrogen blow-pipe flame. It is alkaline to litmus but is not caustic.

On account of its infusibility, magnesia is now extensively used in the manufacture of firebricks, especially for use in the basic Bessemer steel process. The bricks are made of crushed dead-burnt magnesite, mixed with sufficient gently calcined magnesite to give plasticity to the paste formed by mixing the materials with water to permit of molding. The bricks are fired at a red heat before use. Dolomite has been extensively used for this purpose.

Magnesium carbonate $MgCO_3$ occurs native as magnesite. It is found in large compact or granular masses, and, combined with calcium carbonate, as dolomite $(MgCa)\ CO_3$, in immense quantities all over the world. Magnesium carbonate dissolves in water saturated with carbon dioxide.

**Magnesite.**—This mineral is a magnesium carbonate $MgCO_3$. Specific gravity of the crystals 3.1. It crystallizes in a number of different forms, the most common being in rhombohedrons, but the crystals are not of common occurrence; it more often occurs as dull white, compact, or earthy masses, with the appearance of unglazed porcelain or chalk. It is insoluble in water, but dissolves in water containing carbon dioxide in solution.

An average analysis of uncalcined magnesite gives the following:

| | | |
|---|---|---|
| Magnesium carbonate | $MgCO_3$ | 95.00% |
| Alumina | $Al_2O_3$ | .50 |
| Silica | $SiO_2$ | 1.50 |
| Lime | $CaO$ | 1.25 |
| Iron oxide | $FeO$ | 1.75 |
| | | 100.00% |

During the calcining process a loss of 3 to 9% of $MgO_3$ occurs. Calcined magnesite is made into refractory bricks for lining basic steel and electric furnaces. It is also used as non-conducting coverings for boilers, steam-pipes, etc.

**Magnesium,** Mg.—Atomic weight, 24.3. Specific gravity, 1.74. Melting point, 651° C. (1,204° F.). Specific heat, 0.250. Its heat conductivity is 34.3, its electrical conductivity is 34.0, in which silver = 100.

Magnesium occurs abundantly in nature; among the minerals which contain it are magnesite, which is the carbonate, $Mg \cdot CO_3$; dolomite, a double carbonate of magnesium and calcium, commonly known as magnesium limestone. Magnesium also occurs as silicate, combined with other silicates, in a variety of minerals.

Magnesium fuses and volatilizes at a red heat.

It is a malleable, ductile metal of the color and brilliancy of silver. Magnesium in the form of wire or ribbon takes fire at a red heat, burning with a dazzling bluish-white light. The flame of a candle or spirit lamp is sufficient to inflame it, but to insure continuous combustion the metal must be kept in contact with the flame. For this purpose lamps are constructed provided with a mechanism which continually pushes three or more magnesium wires into a small spirit flame. The magnesium flames produce a continuous spectrum, containing a very large proportion of the more refrangible rays: hence it is well adapted for photography.

In dry air, it undergoes little change, and is much less oxidizable than the other metals of the same group in which it belongs chemically. It does not decompose cold water; but if the water be heated to about 90° C. there is a slight evolution of hydrogen.

**Magnesium Carbonate,** $MgCO_3$.—Magnesium shows a marked tendency to form basic salts with carbonic acid. When a neutral magnesium salt is treated with a soluble carbonate, a basic carbonate is precipitated, the composition of which varies according to the conditions under which it is prepared.

Normal magnesium carbonate occurs in nature as magnesite. It crystallizes in the same form as calcium carbonate or is isomorphous with it. It is insoluble in water, but like calcium carbonate it dissolves in water containing carbon dioxide in solution. As a non-conductor of heat, carbonate of magnesia has all the desirable qualities of heat insulation to a greater degree than any other known substance, but

it is not adhesive, and would therefore not be durable if it were used exclusively. Asbestos in fibrous form is fireproof, light and practically indestructible, but it is not a thorough non-conductor of heat; by combining the two materials in proper proportions the asbestos fiber acting as a binder and holding the magnesia in form, on the same principle that hair is used in ordinary plaster, is the method employed in the construction of pipe coverings for high-pressure steam-heated surfaces; it is claimed that heat insulation composed of approximately 85% pure carbonate of magnesia and 15% fibrous asbestos is the lightest, most efficient, durable, and economical covering.

**Manganese,** Mn.—Atomic weight, 55. Specific gravity, 8.00 = 499 pounds per cubic foot. Melting point, 1,225° C. (2,237° F.). Specific heat, 0.120. Manganese is a soft, brittle, grayish-white metal, which oxidizes quickly on exposure to the air, decomposes water slowly at ordinary temperatures, and dissolves easily in acids; it is fully magnetic. Manganese occurs in nature principally in the form of *pyrolusite* or manganese dioxide, $MnO_2$, also known as the black oxide of manganese, which is so intimately associated with iron in nature that few iron ores are free from that element, consequently nearly all commercial iron and steel contain manganese.

Manganese will combine with iron through a wide range of proportions, ferro-manganese, for example, containing as much as 80% manganese. It is always present in pig iron, it acts as a hardener, and makes iron white, crystalline, and brittle. In the foundry the direct effect of combined iron and manganese is less important than the effect of the manganese on the non-metallic elements carbon, silicon, and sulphur in the iron. The hardness of iron castings is attributed to the presence of combined carbon; Hiorns, referring to the fact that manganese causes the iron to go into the combined form, that would naturally point to its having a hardening effect on cast iron; although manganese, by forming an alloy with iron, would harden iron independently of the indirect effect due to carbon.

Carbon is always present in pig iron, and the manganese also present increases the power of iron to combine with carbon at very high temperatures, say 1,400° C. (2,552° F.) so that the higher the manganese the higher is the quantity of combined carbon, hence manganese tends to the production of white pig iron. Manganese prevents the separation of carbon as graphite at temperatures lower than given above. Manganese combines with iron and carbon, forming a double carbide, which is much more stable than carbide of iron, less easily broken up by silicon; the carbon being in the combined state, the presence of manganese has the effect of hardening the iron; but the manganese is readily removed from iron by oxidation, and in this way restrains the oxidation of iron while sometimes permitting the oxidation of other elements combined with it. Silicon combines with manganese to form manganese silicate. Silicon forms a solid solution with iron, and manganese appears to go into solution in the form of a silicide, FeSi. In steel-making a certain amount of silicon is found in the form of silicate slag. Ordinary chemical analysis does not distinguish between silicate and silicide, only the total content of silicon being returned.

Sulphur opposes the formation of graphitic carbon in iron, and thus tends to make iron hard and brittle. It is present as ferrous sulphide, FeS, which is readily soluble in molten iron. Manganese counteracts the bad effects of sulphur, and this, together with its power of reducing oxide of iron, prevents red-shortness. When manganese is added to or is already present in an iron containing sulphur, the manganese decomposes the iron sulphide, forming manganese sulphide, MnS, and liberating iron; thus $FeS + Mn = MnS + Fe$. By mixing pig iron high in manganese with pig iron high in sulphur, a sulphide of manganese is formed, which rises to the surface of the molten metal in virtue of its lower specific gravity and passes into the slag. Hiorns states that it requires 2.6 parts of manganese to remove 1 part of sulphur. If this MnS does not rise to the surface and pass off with the slag, it then remains as intermixed globules scattered through the mass, and if there is enough manganese present all the sulphur will be present as manganese sulphide, and since sulphur, as sulphide of iron, has a strong tendency to keep carbon in the combined condition, the addition of manganese by converting the sulphur into manganese sulphide, tends to soften the iron.

Phosphorus is present in pig iron as phosphide. In steel-making this phosphide is largely removed from iron by a strong, basic slag, in the composition of which is

included oxide of manganese. In the foundry, the brittleness of castings, caused by the presence of phosphorus in the pig iron, is not counteracted by the use of ferromanganese in the ladle.

**Martensite.**—This micro-structure occurring in all hardened steels is not a constituent but a crystalline development in high carbon steel; 0.4% carbon, for example, quenched at a temperature above 765° C., 1,409° F. Freshly broken, such a steel presents a fine granular appearance and is apparently structureless, but under the microscope it is seen to consist of three systems of fibers respectively parallel to the three sides of a triangle and crossing each other frequently. When the metal contains less carbon the needles are longer and more clearly differentiated. With the carbon content at or about the eutectoid proportion, 0.89%, the whole structure consists of this crystalline formation if the quenching has been from a temperature of 800° C., 1,472° F., or thereabout. This characteristic does not follow a definite composition of steel since it is found in all steels with carbon content varying from 0.15 to 2.20% which have been thus heated and quickly quenched.

The exact nature of martensite has been the subject of much discussion. That it is the chief constituent of ordinary hardened steels, that is, of steels quenched from above the critical temperature in water or in an iced solution, is agreed.

Osmond's theory is that in martensite, iron is present chiefly in its beta condition, holding carbon in solution, hence the great hardness of that constituent. Since martensite is magnetic, it must also contain an appreciable quantity of magnetic alpha iron.

Edwards and Carpenter contend that austenite and martensite are in reality the same constituent, namely, a solid solution of carbon in gamma iron, differing only in structural aspect, the needles of martensite resulting from the twinning of austenite caused by the severe pressure exerted upon it during rapid cooling.

Arnold's theory is that martensite, like austenite, is the carbide $Fe_{24}C$, holding in solution ferrite in hypo-eutectoid steel and cementite in hyper-eutectoid steel.

Sauveur, after careful consideration of the evidences at hand, adopts Osmond's theory as the one best supported.

Sexton and Primrose regard martensite as a transition product in the decomposition of austenite, varying in hardness according to its carbon content, being, in fact, a solid solution of iron carbide in one of the allotropic modifications of iron, probably beta. On annealing a steel showing this martensitic structure, the needlelike shapes gradually disappear.

On dissolving the hardened steel in dilute acid, a dense black residue is left which is quite different from the plates of Abel's iron carbide left on dissolving the unhardened steel. High power magnifications show the characteristic martensite structure to be made up of two differently etching portions in almost all cases, except that of the 0.89% or eutectoid steel, when the structure is very minute and practically homogeneous. To this saturated martensite, Professor Howe has given the name of *Hardenite*, which term is often now used synonymously with martensite, which should always be named by its carbon content to indicate its variable nature and physical properties.

**Mercury,** Hg.—Atomic weight, 200. Specific gravity, 13.59. Weight per cubic foot, 848 pounds = 0.49 pound per cubic inch. At ordinary temperatures mercury is liquid; it solidifies at −39° C., −38° F. The specific gravity of the frozen metal is 14.39. Mercury is distinctly volatile at all temperatures above 190° C. It boils at 357° C., 675° F., and is converted into a colorless vapor, which is very poisonous. The specific heat of liquid mercury is 0.033; that of the frozen metal is 0.0319. Expansion of mercury from 0° to 100° C., 32° to 212° F., is 1.018153 volume at 100° C., 212° F., Regnault. Heat conductivity, 1.3; silver = 100.0. Electrical conductivity, 1.5; silver = 100.0. The electric conductivity of pure mercury at 0° C., based on the definition of the international ohm, is 0.017720 times that of copper. The resistivity of mercury is 56.4327 times that of copper.

Mercury has a nearly silver-white color, and a very high degree of luster. When pure, it is quite unalterable in the air at common temperatures, but when heated to near its boiling point it slowly absorbs oxygen and becomes converted into a crystalline, dark-red powder, which is the highest oxide HgO. This monoxide is commonly known as red oxide of mercury or red precipitate, which is slightly soluble in water, com-

municating to the latter an alkaline reaction and metallic taste; it is highly poisonous. When strongly heated, this oxide is decomposed into metallic mercury and oxygen gas.

Mercury is not acted upon by hydrochloric acid, and is almost unaffected by dilute sulphuric acid, but with hot concentrated sulphuric acid it forms $HgSO_4$, a mercuric sulphate. Mercury is dissolved even by cold dilute nitric acid, and is rapidly dissolved in hot nitric acid. It is dissolved by aqua regia with formation of mercuric chloride, $HgCl_2$.

The mercury of commerce, when it comes directly from the furnace, is in most instances nearly pure, but is sometimes contaminated by holding small quantities of other metals in solution. Pure mercury will roll down an inclined surface without forming a pronounced " tail " and without leaving any streak behind it. If a blackish film is left behind, the mercury requires purification. To separate the mercury from its impurities, it is often distilled from an iron retort and again condensed in a vessel containing cold water; a certain portion of the impurities is, however, generally carried over into the receiver.

Certain difficulties are encountered in the use of mercury in the extraction of gold. Sir T. K. Rose enumerates particularly when mercury is agitated with oil, fats, turpentine, many organic substances, sulphur, etc., it is split into minute globules, not easily reunited. This is known as the " flouring " of mercury. Vegetable or animal oils cause more flouring than mineral oils. Coalesence of floured mercury is effected by the action of certain reducing agents, such as water and sodium, the passage of an electric current, or with some loss by the action of nitric acid.

Floured mercury is perfectly white in appearance, like flour, sickened mercury being blackish. The " flouring " of mercury, or minute mechanical subdivision, is due to excessive stamping or grinding.

The " sickening " of mercury is an extreme subdivision caused by chemical means, in which a coating of some impurity is formed over the minute globules of mercury, which are thereby prevented from coalescing, from taking up gold and silver, or from being caught by the plates and wells in the amalgamating machines, as the coating prevents contact between the mercury and other bodies. The impurity may be an oxide, sulphate, sulphide, or arsenide of some base metal.

The base metals usually present in mercury are rapidly oxidized in the air, especially in contact with water; the oxidation is made much more rapid by the presence of any acid in the water, and this acidity is rarely quite absent from battery and mine waters, although it is often neutralized by lime. The metallic oxides thus formed are not soluble in mercury, and they float on its surface in the form of little black scales, which soon form a coating.

Lead is one of the impurities in mercury most to be feared, as the amalgam of this metal tends to separate out of the bath of mercury in which it is dissolved.

Amalgam is the term applied to any mixture of which mercury is the chief constituent. Mercury unites readily with gold, silver, copper, lead, zinc, tin, bismuth, cadmium, palladium, magnesium, potassium, sodium; mercury does not combine readily with nickel, manganese, cobalt, platinum; iron is acted upon very slightly even when hot.

**Molybdenum,** Mo.—Atomic weight, 96.0. Specific gravity, 8.6. Melting point, 2,500° C. (4,500° F.). Specific heat, 0.072. Molybdenum occurs in *Molybdenite*, $MoS_2$, *Wulfenite*, $PbMoO_4$, and *Molybdic ochre*, $MoO_3$, usually containing a considerable amount of $Fe_2O_3$.

The purest molybdenum metal is produced from Wulfenite, but practically the whole of the world's supply of the metal and its compounds is obtained from molybdenite.

When pure and free from more than a trace of carbon, it is softer than steel, malleable, and capable of being forged and welded.

It is attacked by the halogens and by most acids and fused salts, and has not so far been applied to any practical use, except in alloy with other metals.

Ferro-molybdenum and other alloys are produced by the direct electric furnace reduction of molybdenite in admixture with oxide of iron, chromium nickel, or tungsten, the only metals with which it is at present alloyed for technical use.

The addition of molybdenum to steel in the form of the pure metal or one of the

above alloys largely increases its tensile strength, toughness, and fineness of grains and its retention of magnetism.

For the production of high-grade tool steel, it has a value similar to, but greater than, that of tungsten. At present it is mainly employed in crucible steel, and, like many of the steels now being prepared for special purposes, molybdenum steels and molybdenum alloys must be regarded as still on trial as compared with others, although the fact that they are of great value is beyond doubt; molybdenum is now prepared for addition to steel, as 90 to 98% molybdenum powder or fused lump practically free from carbon, as ferro-molybdenum containing 10, 25, 50 and 80 to 85% molybdenum, as an alloy with tungsten, chromium, or nickel.

The following are typical analyses of ferro-molybdenum as now made by the electric furnace:

| | | | | | |
|---|---|---|---|---|---|
| Molybdenum | Mo | 85.80 | 80.00 | 85.00 | 50.00 |
| Iron | Fe | 10.96 | 16.50 | 14.20 | 49.30 |
| Carbon | C | 3.07 | 3.24 | 0.50 | 0.35 |
| Silicon | Si | 0.11 | 0.21 | 0.25 | 0.30 |
| Sulphur | S | 0.05 | 0.02 | 0.03 | 0.03 |
| Phosphorus | P | 0.01 | 0.03 | 0.02 | 0.02 |

The two low-carbon alloys were probably produced by the refining of crude cast ferro-molybdenum by a modification of the process of Moissan, which removes the excess of carbon by heating the powdered metal with molybdenum dioxide or calcium molybdate, with the addition of alumina for production of slag.

Molybdenum combines with the halogens to form a large variety of compounds, including many double halogen salts and various oxy-salts. It forms compounds with phosphorus, boron, silicon, and sulphur, which are of no technical interest except in so far as their presence in molybdenum or ferro-molybdenum is objectionable. —*G. T. Holloway.*

**Nickel,** Ni.—Atomic weight, 58.56. Specific gravity, 8.9 = 550 pounds per cubic foot = 0.317 pound per cubic inch. Melting point, 1,452° C. (2646° F.). Specific heat, 0.10916, Regnault, for temperatures, 14° to 97° C. Pionchon gives the following: at 100° C. = 0.1128, at 300° C. = 0.1403, at 500° C. = 0.1299, at 800° C. = 0.1484, at 1,000° C. = 0.1608.

Nickel is a gray-white metal capable of receiving a high polish; it is about the same hardness as iron, and, like that metal, malleable and ductile. It has about the same fusibility as wrought iron, but is less readily oxidized than that metal. It is slightly magnetic, but loses its magnetic power at about 350° C. The metal in its ordinary condition is brittle, but when it contains a small quantity of magnesium or phosphorus it becomes very malleable. Nickel can be welded, not only to nickel, but also to certain alloys, and to iron and steel. Nickel takes up carbon like iron by cementation, and the carbon may exist both in the combined and in the graphitic form by fusing the cemented metal. It does not possess the property of hardening and tempering like iron. It unites with sulphur, forming nickel sulphide, NiS, which is brass-yellow in color and with arsenic, forming nickel arsenide, NiAs. Nickel is used for the manufacture of various small articles and for coinage. It is largely used for making the alloy known as nickel silver, and it is used for alloying with steel to produce the well-known nickel steel. It is also largely used for covering other metals by the process of electroplating. Commercial nickel was formerly very impure, due to the presence of iron, copper, silicon, sulphur, arsenic, and carbon, which make it hard and brittle. Nickel of very great purity is now made by the Mond process. Nickel unites readily with most metals forming alloys, some of which are of great commercial utility. The most important of these is German silver, for which there is a wide range of proportions; a metal which is to be rolled, pressed, or stamped, the alloy must be tough and malleable; and as whiteness in color is an important consideration, it follows that the metals nickel and zinc must be present in considerable quantity in order to overcome the red color of the copper. Founders whose specialty is the manufacture of German

silver have agreed that the best alloy for beauty, luster, and working properties consists of the following proportions: 46% copper, 34% nickel, 20% zinc.

**Nitrogen,** N.—Atomic weight, 14.01. Specific gravity, 0.971. Air = 1.000. Weight per cubic foot, 0.0784 pound at 0° C., 32° F. = 12.755 cubic feet per pound. Specific gravity (H = 1) = 14.00. The density of atmospheric nitrogen, containing the inert gases, is 0.972. Specific gravity of liquid nitrogen at −194° C. is 0.8084; at −198° C. it is 0.8297. The specific gravity of solid nitrogen at −211° C. is 0.8792; at 253° C. it is 1.0265. Specific heat of liquid nitrogen at −196° to 208° C. is 0.430. Specific heat of gaseous nitrogen between 0° and 200° C., 32° to 392° F., is 0.2348. Critical pressure of nitrogen is 35 atmospheres; critical temperature −146° C.; critical volume 42.6 c.c.; critical density, 0.0236. (Thorpe.) Increase of pressure of nitrogen under constant volume, and final pressure at 100° C., 212° F., when initial pressure at 0° C., 32° F. = 1.0000 is 1.3688. (Regnault.)

The specific heat of nitrogen, water at 0° C., 32° F. = 1.000, is: For equal weights at constant pressure, 0.2440. At constant volume, 0.1740; this is the real specific heat. For equal volumes at constant pressure, water at 0° C., 32° F. = 1.0000; air = 0.2377; nitrogen = 0.2370. At constant volume, water at 0° C., 32° F. = 1.0000; air = 0.1688; nitrogen = 0.1690. (D. K. Clark.)

Latent heat of vaporization at boiling point is 50.4 cal.

Coefficient of expansion of liquid nitrogen varies from 0.002996 at 11° C. −132° abs. under 6 mm. to 0.003574 at 100° abs. under 1000 mm.

Solubility: Liquid oxygen at −195.5° C. dissolves 458 times its volume, or 50.7% of its weight of gaseous nitrogen. Solubility in water:

| | | | | | | |
|---|---|---|---|---|---|---|
| Temperature | 0° C. | 10° C. | 20° C. | 30° C. | 40° C. | 50° C. |
| C.c. per liter | 23.00 | 18.54 | 15.54 | 13.55 | 12.15 | 11.02 |

Wood charcoal absorbs ten times as much nitrogen at −185° C. as at 0° C.

Nitrogen is a colorless, odorless, and tasteless gas. It is found in the free state in the atmosphere, of which it constitutes about four-fifths by volume. It is a permanent gas in that no pressure will liquefy it at any temperature lying above the "critical point" of −146° C. At or a little below this temperature, 35 atmospheres of pressure will reduce it to a liquid. Nitrogen plays no active part in the processes of combustion and of animal respiration; in either case it appears to act only as an inert diluent of the oxygen. In the case of respiration, no animal could live healthily for any considerable period of time in pure oxygen, and we know of no other diluent which could be substituted for the nitrogen without poisonous effects.

Atmospheric nitrogen, in an indirect way, contributes toward the building up of nitrogenous organic matter. Every process of ordinary combustion probably, and every electric discharge in the atmosphere certainly, induces the formation of some nitric acid, which by combining with the atmospheric ammonia becomes nitrate of ammonia. The compounds of nitrogen may be arranged under the heads of ammonia, nitrates, nitro-compounds, organic nitrogen compounds, and cyanides.

**Occlusion** is the process of absorption or condensation of gases within the pores of a substance. Metals have the power of absorbing gases; thus, hydrogen is capable of penetrating platinum and iron tubes at a red heat. Platinum wire or plate, at a low, red heat, can take up 3.8 volumes of hydrogen measured cold, and palladium foil condenses as much as 643 times its volume of hydrogen at a temperature below 100° C. In the form of sponge, platinum absorbed 1.48 times its volume of hydrogen and palladium 90 volumes. The occlusion of gases by metals is well known, and the importance of this action on iron, especially in regard to oxygen, is thus pointed out by Hiorns in the effects of various elements on steel: The absorption and retention of oxygen at the conclusion of the Bessemer blow is a powerful factor that has to be reckoned with, owing to its intimate association with the iron and its profound influence on the properties. The precise manner in which it exists, whether as a dissolved gas or an oxide, is not yet ascertained; at any rate, oxygen may be readily removed from iron by means of manganese and other deoxidizers. Carbonic oxide is another gas readily absorbed by iron, and its decomposition and recomposition are supposed to play an important part in the process of cementation. Silicon and manganese appear to be able to keep carbonic oxide in solution in iron. The quantity of oxygen retained

by iron is probably small, seldom more than 1.0%, and often very much less, but this small quantity is very powerful in affecting its physical properties.

**Open-Hearth Process.**—In this process for making steel a regenerative furnace hearth is used of the reverberatory type. A feature of this design of furnace is that the waste heat is employed to heat up both the gaseous fuel and the air requisite to burn it before they are introduced into the furnace or chamber where they undergo combustion. This is effected by making the exit gases pass through regenerators consisting of piles of fire bricks stacked loosely together so as to expose as much surface as possible. Four such piles of fire bricks, in separate chambers, are employed, two being heated up by the waste gases escaping from the melting furnace, while the other two are in use, the one for heating the gaseous fuel supplied by a gas producer, the other for heating the air requisite for the combustion of the gas. By suitable valves the waste gases are shunted from the first to the second pair of regenerators, while simultaneously the gas and air are changed from the second to the first pair; as the temperature at which the gas and air enter is close to that at which the products of combustion leave the furnace, while the regenerators are being heated up, the temperature of the combustion chamber continually rises with each reversal of the currents through the regenerators; so that ultimately the only limit to the temperature attainable is the refractoriness of the materials of which the furnace is constructed; as the melting point of iron is 1,520° C., and that of the best quality of bauxite fire bricks about 1,820° C., there is a working margin of 300° C. between melting the iron and fusing the exposed surface of the lining having equivalent resistance to bauxite brick.

The furnace hearth is not unlike a shallow concave dish with sloping sides carried up to the level of the charging door. The depth of the hearth below the level of the charging doors is such as to provide for a depth of about 12 inches of molten metal for furnaces 6 to 12 tons capacity, up to about 24 inches for 50-ton furnaces, or larger. An acid open-hearth furnace will have a silica fire-brick lining with a top coating of refractory sand and clay rammed into place, the furnace to be afterward gradually brought to full furnace heat. The roof is lined with silica fire brick.

**The Acid Open-Hearth Furnace** is principally a melting furnace, and none of the impurities in the metal are removed except carbon and silicon. The consequence is that the quality of the steel made is dependent upon the quality of the metal used. Pig iron for acid open-hearth use may follow the composition prescribed for the acid Bessemer process, that is, not over 2.0% silicon, total carbon about 3.5%, with less than 0.10% phosphorus and sulphur, because neither of these two is reduced in the process. In making a steel suitable for boiler plate, in a small furnace, about 25% of the entire charge was melted in the hearth and brought to a high heat when wrought iron and mild steel scrap previously heated to a bright red was then immersed in the bath and allowed to dissolve in it. When the carbon in the whole mixture had been brought to the desired point, *i.e.*, practically eliminated, the silicon had also been reduced, either by fusion or by chemical action to the minimum amount, say from 0.01 to 0.05%. Ferro-manganese previously heated was put into the bath, the whole mass of metal thoroughly stirred and then run out into a large ladle, from which it was poured into ingot molds. During this process silicon and carbon were oxidized together with any other oxidizable impurities and passed into the slag, but most of the sulphur and practically all of the phosphorus remained in the metal. As this steel was made on a silica or acid bottom, the slag was therefore necessarily acid, and would not combine with the phosphorus as it oxidized in the steel, the latter element therefore immediately recombined with the metal.

**The Basic Open-Hearth Furnace** differs from the acid hearth mainly in the character of its lining. As its name indicates, the metal is melted on a basic bottom, which may be formed of lime or magnesia. In either case additions of lime are made to the bath to insure a highly basic slag, which will be sure to hold all the phosphorus as fast as it is oxidized from the metal. Pig iron for basic open-hearth use should contain not more than 1.0% silicon; the sulphur should always be low, not more than 0.10% if possible; phosphoric irons may contain up to 3.0% phosphorus, depending upon the locality; usually, however, it is below 1.5%. The basic process works the practical elim-

ination of phosphorus in iron, it matters little therefore what its percentage is in the pig so long as this is accurately known at the time of charging the furnace.

The reactions involved in oxidation of phosphorus in general consist, first, in the formation of $P_2O_5$, and second, the combination of this oxide with lime, forming calcium phosphate, which latter is held in a slag high in iron oxide. The oxygen for the removal of phosphorus comes largely through the medium of iron oxide and furnace gases; but not from lime, and the lime itself cannot prevent the reduction of phosphorus back into the metal out of the slags from which iron oxide is largely reduced. The temperature of the furnace is maintained by combustion of the gas in the furnace chamber, and this atmosphere is oxidizing to a greater or less extent. Any control over the reducing conditions must therefore come from reducing agents in the metal, and limited control, if any, can be had over the action of agents such as silicon or dissolved carbon. Since iron oxide cannot be kept from forming in the slag under influence of the furnace atmosphere, the silicon and carbon in the metal are the agents to be relied upon to prevent oxidation. To hold the strongly acid oxide of phosphorus in the slag requires a fluxing agent having strong affinity for phosphorus and strongly basic in chemical nature, like lime. Calcium phosphate can be reduced from the slag back into the metal when the conditions of equilibrium between the iron oxides in the slag are such as to reduce the amount of iron oxide below a certain limit. Silicon is such a strong reducing agent that it must be oxidized out of the metal before the phosphorus is attacked. The influence of carbon, an important reducing agent in the metal, is largely dependent on the temperature, its affinity for oxygen being less than that of phosphorus at low temperatures, and greater at temperatures above 1,450° C. Lime is necessary to hold the phosphorus in the slag. Combustion is the source of heat and iron oxide is always present and usually in large amounts; silicon oxidizes before phosphorus, and the oxidation of carbon before or after phosphorus is determined by the temperature. —*Albert E. Greene.*

The various reactions in the removal of phosphorus from iron have been thus summarized by Mr. Greene:

1. At temperatures below 1,450° C., phosphorus in pig iron has greater affinity for oxygen than has the carbon in the pig iron, but less affinity for oxygen than solid carbon in the presence of pig iron.
2. At temperatures above 1,450° C., the affinity of the carbon dissolved in iron for oxygen becomes greater than the affinity of phosphorus in the iron, and the dissolved carbon can reduce calcium phosphate in the slag.
3. Phosphorus oxidizes in presence of lime, and iron oxide to calcium phosphate in absence of silicon or solid carbon.
4. Silicon reduces calcium phosphate nearly always, but there may be a range of temperature below 1,450° C. where phosphorus oxidizes to calcium phosphate more easily than silicon to calcium silicate.
5. Solid carbon will reduce calcium phosphate contained in a slag or bath of iron, and phosphorus will go into the metal.
6. Calcium phosphate can form without oxidation of iron in presence of carbon dissolved in pig iron at low temperature.
7. Calcium phosphate can form without oxidation of iron in absence of carbon and silicon at high temperatures, that is, above 1,450° C.
8. Iron oxide can be reduced without reduction of calcium phosphate contained in the same slag.

**The Talbot Process** is a continuous basic open-hearth process developed by Benjamin Talbot (1899). The general practice in open-hearth working is to charge solid pig iron and scrap into the furnace in which hours of valuable time are consumed before the furnace contains the necessary heat to enable the ordinary slag additions to be made in order to purify the charge and convert the metal into steel of the desired quality. In the Bessemer process what is gained in time and labor is lost in yield; the gain in yield in the open-hearth practice is largely annulled by loss in time and cost of labor. To approach in any way the rapidity of Bessemer practice on the one hand, and the yield of the open hearth on the other, Mr. Talbot considers the following conditions essential to success:

1. The use of fluid metal from blast furnace, mixer or cupola, direct.

2. The oxidation of the metalloids should be effected entirely by means of solid oxides of iron, and not by the action of the air.

3. Maintaining by some suitable means a large reserve of heat to keep the oxidizing slags and metal in a fluid condition, and to insure the rapid removal of the metalloids from the molten pig iron.

A trouble with hearth and bottoms of furnaces, both acid and basic, is due to the action of the slag, and not to the metal. If after considerable work the face of a basic hearth is examined, it will be found to be nearly of the same composition as the slag; the effect is to render the hearth less refractory, therefore less able to withstand the heat of the finished steel when hot enough to pour. To overcome this drawback the slag must be prevented from washing and impregnating the lower portion of the hearth every time the furnace is tapped. This is accomplished by flowing the slag off from the surface of the bath through a slag spout at the foreplate level. A tilting furnace permits any quantity of metal or slag to be poured out when desired. The furnace tilts in both directions, so that slag can be poured off from the opposite side to the metal. This tilting furnace permits the withdrawal of metal or of slag at any time, and as the slag does not come in contact with the lining of the hearth, the latter is not softened and the refining operations can be made continuous, the usual runs extend through a period of six days.

**Oxides.**—An oxide is the product of the combination of oxygen with a metal or metalloid. In the former case a base is formed, in the latter an acid radical. An acid contains hydrogen in its composition; a base contains a metal. When the acid acts upon a base the hydrogen and the metal exchange places. The products of the action of an acid upon a base are first water, and, second, a neutral substance called a salt. Oxides may therefore be divided into three classes: acid, neutral, and basic; the first and third being capable of uniting with one another in definite proportions and forming compounds called salts. To distinguish between different oxides, the name of the element with which the oxygen is in combination is prefixed; thus, iron oxide, zinc oxide, etc.

For chemical action to take place between two bodies it is necessary that they be in contact, and, generally speaking, that one of them should be in the state of liquid or gas. Oxidation is the chemical change which gives rise to the formation of oxides brought about by the action of oxygen acids, water, or free oxygen. In all cases of oxidation heat is developed, but it depends altogether upon the rapidity with which the oxidation is effected whether light is also produced, that is to say, whether what is termed combustion takes place, such as the burning of coal, or a slow oxidation, such as the rusting of iron.

Protoxides are compounds each having one equivalent of oxygen with another element; thus, protoxide of iron or ferrous oxide, $FeO$, is composed of one equivalent of iron and one of oxygen.

Sesquioxides require three equivalents of oxygen to two of a metal; thus, sesquioxide of iron or ferric oxide, $Fe_2O_3$, is composed of two equivalents of iron with three equivalents of oxygen.

When an element forms more than one compound with oxygen, suffixes are used to distinguish between them; thus, among the oxides of copper there are two represented by the symbols $Cu_2O$ and $CuO$. The first of these symbols, $Cu_2O$, is that of copper or cuprous oxide, the suffix *ous* being added to show that it contains for a given quantity of the other element a smaller quantity of oxygen. The second symbol, $CuO$, stands for copper or cupric oxide, the suffix *ic* indicates that the proportion of oxygen is larger.

Metallic oxides are the most important of all the compounds of the metals; in many cases these occur naturally as ores, most of which are readily fusible; those of lead and bismuth at a low red heat; those of copper and iron at a white heat; those of aluminium are fused in the electric furnace; while calcium oxide does not fuse at any temperature at our command.

There are three oxides of iron of metallurgical importance: The ferrous oxide $FeO$, a monoxide, basic in its properties and which will neutralize acids; it is isomorphous with magnesia, zinc oxide, etc. It is almost unknown in a separate state from its

readiness to absorb oxygen and pass into the sesquioxide. This oxide is the principal base in all iron slags produced in the refining of iron.

Ferric oxide, $Fe_2O_3$, or the sesquioxide of iron, is feebly basic; it is isomorphous with alumina. It occurs native, crystallized, as specular iron ore, it also occurs as hematite, forming one of the most valuable ores of iron. As hematite, it is a black, crystallized substance with a high luster; otherwise, it has a red or reddish-brown color. It is easily reduced at a high temperature by carbon or hydrogen. Ferric oxide is a powerful oxidizing agent; like alumina, it can act as an acid in combination with a stronger base, such as lime.

Magnetic oxide, $Fe_3O_4$, a ferrous-ferric oxide; also called black oxide of iron. It is found in nature as the mineral magnetite and lodestone. Chemically, it may be regarded as a compound of ferrous oxide, FeO, with ferric oxide, $Fe_2O_3$, in which the ferrous oxide plays the part of a base and the ferric oxide that of the acid.

Oxides of the non-metals are of considerable importance in the arts. Among familiar examples occur carbon monoxide, CO, and carbon dioxide, $CO_2$, both products of combustion, the former of incomplete and the latter of complete combustion. Sulphur combines in two proportions, forming the oxides $SO_2$, sulphur dioxide, and $SO_3$, sulphur trioxide. Sulphur dioxide, or sulphurous oxide, is the only product formed when sulphur is burned in dry air or in oxygen; with water it forms sulphurous acid, $SO_3H_2 = SO_2 + OH_2$, much used as a bleaching agent; it is also used as a disinfectant.

**Oxygen,** O.—Atomic weight, 15.96 (formerly 16). Specific gravity, 1.106, air = 1.000. Weight per cubic foot, 0.089 pound; 1 pound = 11.202 cubic feet.

Specific heat: For equal weights at constant pressure, 0.2182, water = 1.00. At constant volume, 0.1559, water = 1.000 (real specific heat). For equal volumes at constant pressure, 0.2412, air = 0.2377. At constant volume, 0.1723, air = 0.1688.

Oxygen exists in a free and uncombined state in atmospheric air, which consists of a mixture of 23 parts of oxygen, 77 parts of nitrogen by weight; or 21 parts oxygen and 79 parts of nitrogen by volume. When pure, oxygen is colorless, tasteless, and inodorous. It is the sustaining principle of animal life and of all the ordinary phenomena of combustion.

Oxygen forms a large proportion of the solid crust of the earth, which has been variously estimated at from 44 to 48%; it forms eight-ninths of water and about one-fifth of the air. It occurs in combination with carbon and hydrogen, or with carbon, hydrogen, and nitrogen in the substances which go to make up the structure of living things, whether vegetable or animal. The compounds formed by the direct union of oxygen with other bodies bear the general name of oxides; these are very numerous and important.

Oxygen was liquefied by Wroblewski in 1883. The following data for oxygen is from *Comptes Rendus*, Vol. XCVI:

At temperature of − 131.6° C. (− 204.9° F.) begins to liquefy at 25.5 atmospheres, 375 pounds per square inch.

At temperature of − 133.4° C. (− 208.1° F.) begins to liquefy at 24.8 atmospheres, 365 pounds per square inch.

At temperature of − 135.8° C. (− 212.4° F.) begins to liquefy at 22.5 atmospheres, 331 pounds per square inch.

The liquid oxygen was colorless and transparent, very mobile, and giving a sharp meniscus.

**Pearlite.**—When a steel having about 0.9% carbon is brought to a temperature above red heat and allowed to cool slowly and a prepared section of this steel is examined under the microscope, there will be exhibited a structure made up usually of alternate plates of ferrite and cementite paralleling each other; this structure is called pearlite because the display of colors, especially under oblique illumination, shows a definite pearly luster. The cementite plate in the structure of pearlite consists chiefly of carbide of iron, $Fe_3C$; the other plate is ferrite, or practically pure iron; ferrite is the softest constituent of iron.

Pearlite is the eutectic of iron and carbide of iron, $Fe_3C$, and contains about 0.85% carbon. Cementite and ferrite usually unite in definite proportions to form pearlite, and any excess of cementite or ferrite remains uncombined. Pearlite may therefore

be considered an intimate mixture of ferrite and cementite; but steel containing 0.89% carbon is practically all pearlite.

The amount of pearlite in low-carbon steel increases progressively with the carbon contents. Doubling the amount of carbon doubles the proportion of the iron carbide in the steel, and since the amount of pearlite is apparently also doubled it follows that iron carbide and ferrite must unite with each other in fixed ratio to form pearlite; in other words, that pearlite always contains the same proportion of carbide and hence also of carbon.—*Sauveur.*

In the case of steel containing 0.9% carbon, as above, all the carbon is combined with the iron to form cementite, the percentage of cementite will be the percentage of carbon multiplied by 15, in this case $.9 \times 15 = 13.5$; the difference, $100 - 13.5 = 86.5$, is the ferrite, and the amount of ferrite in the pearlite is the amount of cementite multiplied by 6.4.

Suppose steel to contain less than 0.9% carbon, which has also been cooled from a high temperature, its structure will be different. Pearlite will be present, but it will not occupy the whole area. If there be 0.1% carbon, the area occupied by the pearlite will be 11.1%, and this pearlite will contain all the carbon. The remainder of the mass will be carbon, free iron, or ferrite, so that in this case (0.1% carbon) the amount of cementite containing all the carbon will be 1.5%, and this will be associated with 9.6% of ferrite to make up the pearlite, and there will be 88.9% of excess or free ferrite; that is, ferrite not in the pearlite.

White cast iron consists of about two-thirds pearlite and one-third cementite; while spiegeleisen contains about equal quantities of each.

**Phosphorus,** P.—Atomic weight, 30.96. Specific gravity, 1.80. Melting point, 44° C. (111.4° F.), and boils at 280° C. (536° F.). Specific heat, 50° to 86° F., 0.189, from 32° to 212° F., 0.250. In the smelting of iron, the phosphorus present in either the ore, the flux, or the fuel, is almost entirely taken up by the pig iron whether it be white or gray. Foundry irons contain from 0.25% to 1.25% phosphorus. It has little effect on the condition of the carbon, but it makes the metal harder and diminishes the color of gray irons. It increases the fluidity of cast iron, and renders the metal more suitable for the production of fine castings. For good strong castings the amount of phosphorus should not exceed 0.50%, and less for those of the highest quality. For fine castings, where strength is not of first importance, 1.50% phosphorus may be present with advantage. A moderate amount of phosphorus, while increasing the fluidity, also lessens the shrinkage of a casting. As a rule the amount of phosphorus should not exceed 1.0%.—*Hiorns.*

**Platinum,** Pt.—Atomic weight, 194.3. Specific gravity, 21.50. In the shape of foil and wire, the density of platinum varies from 21.2 to 21.7, and that of platinum sponge from 16.32 to 21.24. Melting point, 1,755° C. (3,191° F.). Specific heat, 0.032, between 0° and 100° C. Coefficient of linear expansion, 0.0000089. The coefficient of expansion of platinum is given as 0.00000907 at 50° C., and as 0.00001130 at 1,000° C. This is less than that of any other metal. The tensile strength of platinum (hard) is given as 265,000 pounds per square inch. Its thermal conductivity, silver = 100, is 0.166. Electrical conductivity, silver = 100, is 13.5 at 0° C. The metal is not so white as silver, having a grayish tinge, but its luster is very little less brilliant in polished specimens. The color of finally divided platinum, however, is black. It is harder than copper, silver or gold, being 4.3. Its tenacity is between those of silver and copper. It is malleable and ductile, but the presence of certain impurities decreases the quality; for instance, 0.03% silicon makes platinum hard and brittle, while small quantities of the metals generally associated with platinum, such as palladium, irridium, etc., reduce its ductility.

Platinum is not changed by air, water, or steam at any temperature. *Unit of light:* The unit called the platinum standard of light, sometimes improperly called an absolute unit, is the light emitted perpendicularly from a square centimeter of surface of melted platinum at the temperature of its solidification. It is often called the *violle.* This was virtually adopted by an International Congress, but never came into use, and seems to have been abandoned. Its value is not known definitely, but is approximately 20 candles.—*Hering.*

**Potassium,** K.—Atomic weight, 39. Specific gravity, 0.86. Weight per cubic foot, 54 pounds = 0.031 pound per cubic inch. Melting point, 62° C., 144° F. It volatilizes at a red heat. Specific heat, 0.1662. Heat conductivity, 45; electrical conductivity, 17; silver = 100 in each case. Potassium is one of the metals of the alkalies; it is a brilliant white metal with a high degree of luster; at the common temperature of the air it is soft, and may be easily cut with a knife, but at 0° C., 32° F., it is brittle and crystalline. It melts completely at 62.5° C., 144° F., and distills at a red heat, about 700° C., 1,292° F. Exposed to the air it oxidizes instantly, a tarnish covering the surface of the metal, which quickly thickens to a crust of caustic potash.

It attracts oxygen with avidity on exposure to the air, but when thrown upon water it decomposes it with sufficient energy to ignite the liberated hydrogen, burning with a purple flame, yielding an alkaline solution. The heat developed in the decomposition of water by potassium is 43,000 B.t.u. In contact with any combustible body it undergoes decomposition with great rapidity; five-sixths of the oxygen being available for the oxidation of the combustible substance, the nitrogen is evolved in a free state.

It occurs as a constituent of many minerals; orthoclase or ordinary feldspar is an aluminium potassium salt; when vegetable material is burned, the potassium originally taken up by the plants remains behind, in the ashes, as potassium carbonate. Enormous quantities are obtained from carnellite, a double chloride of potassium and magnesium found at Stassfurt, Prussia, in a layer about 140 feet thick. The Stassfurt potassiferous minerals owe their industrial importance to their solubility in water and consequent ready amenability to chemical operations.

Potassium hydroxide, OKH, commonly called caustic potash, is a brittle white substance, very deliquescent, and soluble in water. The solution of this substance possesses, in the very highest degree, the properties termed alkaline; it restores the blue color to litmus which has been reddened by an acid; it neutralizes completely the most powerful acids. It rapidly absorbs carbonic acid from the air, hence it must be kept in closely stoppered bottles. It is not decomposed by heat, but volatilizes undecomposed at a very high temperature. It is the strongest of the bases. It decomposes the salts of all other bases.

Potassium oxide: Potassium combines with oxygen in three proportions, forming a monoxide $OK_2$; a dioxide, $O_2K_2$; and a tetroxide, $O_4K_2$; besides a hydrate, OKH, corresponding to the monoxide.

Potassium nitrate, $KNO_3$, commonly called saltpeter, crystallizes in six-sided prisms; it is soluble in seven parts of water at 62° F., and in its own weight of boiling water. It is saline to the taste, and is without action on vegetable colors. It fuses at about 334° C., 633° F., to a colorless liquid, which solidifies on cooling to a translucent, brittle, crystalline mass. If instead of being allowed to cool, the heat is continued and increased in temperature the molten mass will be completely decomposed, yielding a large volume of oxygen at the expense of the oxygen of the nitric acid.

As an oxidizing agent, in metallurgy, potassium nitrate, when thrown upon the surface of many metals in a state of fusion, is instantly decomposed, and rapid oxidation of the molten metal occurs, the sulphur of the metallic sulphides is converted into sulphurous acid and the metals into oxides.

Gunpowder consists of 75% potassium nitrate; 15% charcoal; 10% sulphur; when these are intimately mixed and otherwise prepared, the compound forms a stable commercial article, the chief value of which is due to the fact that upon ignition by a spark combustion begins, the necessary oxygen being supplied by the powder itself, independently of the oxygen of the air, and this oxidation is so rapid, and the evolution of gases so sudden, that a violent explosion occurs. This has been explained in the whole of the oxygen of the potassium nitrate being transferred to the carbon, forming carbon dioxide, the sulphur combining with the potassium, and the nitrogen being set free; but analysis of the actual products of the combustion of gunpowder shows the reaction to be much more complicated than this.

Potassium chlorate, $KClO_3$, is soluble in about twenty parts of cold and two of boiling water; the crystals are anhydrous, flat and tabular. When heated it gives off the whole of its oxygen gas and leaves potassium chloride. Its melting point is 354° C., 669° F. In consequence of the ease with which it gives up its oxygen, the chlorate

is an excellent oxidizing agent, especially in assaying. Its chief use is in the preparation of oxygen and in the manufacture of matches and fireworks.

Potassium chloride, $KCl$, is a salt which is commonly known as muriate of potash. It closely resembles common salt in appearance, assuming the cubic form of crystallization. The crystals dissolve in three parts of cold, and in a much smaller quantity of boiling water; it melts at 734° C., 1,353° F., and volatilizes at a much higher temperature. Analysis of potassium chloride: 98.58% $KCl$; 0.22% $NaCi$; 0.07% $MgCl_2$; 0.12% $MgSO_4$; 0.24% $CaSO_4$; 0.31% insoluble; 0.46% water.

Potassium cyanide, $KCN$. Carbon and nitrogen do not, under ordinary circumstances, combine, but when brought together at very high temperatures in the presence of metals they combine to form compounds known as *cyanides*. Potassium cyanide is formed when nitrogen is passed over a highly heated mixture of carbon and potassium carbonate. Potassium cyanide forms colorless cubic or octohedral crystals, deliquescent in the air, and exceedingly soluble in water. It is readily fusible, and undergoes no change at a red heat when excluded from the air.

As a flux, potassium cyanide is valuable on account of the facility with which it fuses and the readiness with which it reduces many metallic compounds when mixed with carbonate of soda. Common cyanide is preferable as a reducing agent because it contains carbonate of potash.

Amalgam: Potassium combines directly with mercury with evolution of heat. When containing 70 to 96 parts of mercury to 1 part of potassium, the amalgam is crystalline. With 30 parts of mercury it is hard and brittle. When heated to 440° C., 824° F., they all leave a crystalline amalgam of the composition $HgK_2$, spontaneously inflammable on exposure to air, but all the mercury is evolved below a red heat. A crystalline amalgam of the composition $Hg_{24}K_2$ has been prepared.

It is the most electro-positive element known with the exception of cæsium and rubidium, and is an extremely powerful reducing agent. Hence the use of potassium for the preparation of less electro-positive elements, such as boron, silicon, magnesium, aluminium, etc., for the reduction of gases containing oxygen out of organic and other compounds.

**Reduction** is the removal of oxygen from a compound; it is the opposite of oxidation. A reducing agent is any substance which has the power to abstract oxygen. Such an agent may act by adding hydrogen to an organic body, thus: Ethene oxide, $C_2H_4O + HH = C_2H_6O$, alcohol; or by removing oxygen without introducing anything in its place, thus: Benzoic acid, $C_7H_6O_2 + HH = OH_2 + C_7H_6O$, benzoic aldehyde. Any substance which has the power to add oxygen to a substance, or to decompose it by the action of oxygen, is called an oxidizing agent.

**Semi-steel** is a variety of cast iron; it is usually made by placing on top of the regular charge of pig and scrap iron in the cupola an additional charge of 15 to 25% of mild steel scrap; then melting all down into a common mixture. The total carbon in the resultant semi-steel is only slightly different from that which would have resulted by melting the iron unmixed by steel; but a change does occur during the melting in the conversion of much of the graphitic carbon into the combined state. The silicon in the iron will be much reduced by its admixture with the molten steel. Crushed ferro-manganese should be strewn in the ladle and the molten metal from the cupola allowed to flow upon it. The resultant metal will be harder and tougher than cast iron, and will also be of higher tensile strength.

**Silica,** $SiO_2$, is a non-metallic oxide of silicon. It contains 28 parts silicon and 32 parts oxygen; it is the only known oxide. This oxide is much used in the reduction of metals from their ores, being the chief slag-forming substance. It is essentially an acid oxide, forming salts with basic metallic oxides. When heated with bases, especially those which are capable of undergoing fusion, it unites with them and forms salts. The various slags in steel making are chiefly composed of silicon, $SiO_2$, together with lime, $CaO$; alumina, $Al_2O_3$; manganese oxide, $MnO$; ferrous oxide, $FeO$.

The list of oxides, both metallic and non-metallic, is very large, but the above will serve to show the general characteristics of familiar examples.

**Silicon,** Si.—Atomic weight, 28. Specific gravity, 2.25 = 140 pounds per cubic foot. Melting point, 1,420° C. (2,588° F.). Specific heat, 0.177. Silicon does not

occur in nature in a free state. It occurs chiefly in the form of the dioxide $SiO_2$, commonly called silica, or silicon dioxide; and in combination with oxygen and several of the common metallic elements, particularly with sodium, potassium, aluminium, and calcium, in the form of silicates. Next to oxygen, it is the most abundant element in nature.

Silicon is ordinarily described as a non-metal, very hard, dark brown in color, a non-conductor of electricity, lustrous, not readily oxidized, and soluble in all ordinary acids, with the exception of hydrofluoric.

In foundry practice silicon pig irons have always had the reputation of imparting fluidity to other brands, and naturally this was at first supposed to be owing to the silicon added. Hadfield shows that this is not directly so, and that it is from the fact that the silicon present causes an increase in the quantity of graphite, and consequently a more fluid cast iron. Silicon is not, therefore, directly the cause, except by its indirect action on the carbon.

Silicon is said to resemble carbon in its general properties; it was formerly believed to exist like carbon in a graphitic, amorphous, and combined form. Holgate, after making many analyses, states that he has never found any evidence as to the existence of graphitic silicon in ferrosilicon alloys.

Pig iron, with a certain amount of silicon, is necessary for the acid Bessemer process, as by far the greater part of the heat required for the conversion must come from the silicon contained in the iron. The higher the percentage of silicon the hotter the charge.

**Silver,** Ag.—Atomic weight, 107.9. Specific gravity, 10.53. Weight per cubic foot, 657.07 = 0.380 pound per cubic inch. Melting point, 960.5° C. (1,761° F.). It volatilizes appreciably at a full red heat; in the oxyhydrogen flame it boils, with formation of blue vapor. Specific heat, 0.056. Latent heat of fusion, 21.07 cals., 37.93 B.t.u. Coefficient of linear expansion, 0.00001079 C. (0.00001943 F.). Heat conductivity, 100. Electrical conductivity, 100. It is the best conductor of both heat and electricity known. The tensile strength of silver (wire) is about 42,000 pounds per square inch.

Silver is a white metal with a high luster. It is exceedingly malleable and ductile. It is harder than gold and softer than tin. It does not tarnish by air and moisture, but in air contaminated with ever so little sulphuretted hydrogen it gradually draws a black film of sulphide. It does not oxidize at any temperature, but the fused metal readily absorbs oxygen if exposed in the air; upon solidification, however, the oxygen thus absorbed is disengaged, excepting a trace, perhaps, which remains permanently in the metal. The addition of 2% copper is sufficient to prevent the absorption of oxygen.

Water and ordinary non-oxidizing aqueous acids generally do not attack silver in the least, hydrochloric acid excepted—which, in the presence of air, dissolves the metal very slowly as chloride.

Aqueous nitric acid dissolves the metal readily as nitrate; hot vitriol converts it into a magma of crystalline sulphate with evolution of sulphurous acid.

Silver is proof against the action of caustic alkali-lyes, and almost so against that of fused caustic alkalies even in the presence of air. It ranks in this respect next to gold, and is much used to make vessels for chemical operation involving the use of fused caustic potash or soda.

**Sodium,** Na.—Atomic weight, 23. Specific gravity, 0.9735. Weight per cubic foot, 60.75, or 0.035 pound per cubic inch. Melting point, 97.5° C., 207.5° F. Boiling point, 825° C., 1,517° F. Specific heat at −28° C., −18°.4 F., 0.290. Heat conductivity, 36.5. Electrical conductivity, 28; silver = 100, in both cases. It occurs in nature in large quantities as chloride, constituting the mineral rock salt; as sodium nitrate or Chile saltpeter; as a double fluoride of aluminium and sodium called cryolite. It also occurs as the sulphate glauberite, and as borax or tincal; sea water contains about 2.6% of sodium chloride.

Sodium is an alkaline metal; freshly cut it exhibits a silvery metallic luster, which rapidly disappears on exposure to air. At a temperature of −20° C., −4° F., sodium is hard; at 0° C., 32° F., it becomes ductile; and at the ordinary temperature it is

soft like wax. It oxidizes rapidly when exposed to moist air, but can be distilled unchanged in air or even oxygen provided all traces of moisture be excluded. Heated in the air, sodium takes fire and burns with a yellow flame, forming a mixture of oxides. Thrown on cold water it swims on the surface, disengaging hydrogen and dissolving, but not evolving, sufficient heat to ignite the gas. If water at 60° C., 140° F., be used, or the free motion of the metal be hindered by increasing the viscosity of the liquid by the addition of gum or starch, the evolved hydrogen ignites, burning with a characteristic yellow flame.

Sodium is used for the purpose of isolating some elements whose oxides can not easily be reduced, such as aluminium, magnesium, boron, and silicon.

Alloys of sodium with different metals have been prepared, the most important being those with potassium. These are liquid at ordinary temperatures and resemble mercury in appearance.

Oxides: Only two well-defined oxides of sodium are known, a monoxide and a dioxide.

Sodium monoxide, $Na_2O$, or anhydrous soda, is produced, together with dioxide, when sodium burns in the air, and may be obtained pure by exposing the dioxide to a very high temperature. Sodium monoxide is a white hygroscopic substance of specific gravity 2.27, and melts at a red heat. Hydrogen reduces it to a metal at 170° to 180° C. 338° to 356° F.

Sodium dioxide, or peroxide $Na_2O_2$, also known as caustic soda, is obtained when the metal is burned in an excess of air or oxygen. Pure sodium dioxide is yellow. It absorbs carbon dioxide with formation of sodium carbonate and liberation of oxygen; a mixture of this dioxide with potassium peroxide is used in life-saving apparatus to regenerate air contaminated by respiration. Charcoal and the alkaline earth carbides reduce it to metallic sodium at a temperature of 300 to 400° C.

Sodium carbonate, $Na_6CO_3$, or soda, is made from sodium chloride, NaCl, or common salt. The anhydrous sodium carbonate usually presents itself in the form of a white, opaque, porous solid, with specific gravity of 2.65. It fuses at 818° C., 1,504° F., into a colorless liquid. On fusing it loses some of its carbonic acid, and at a bright red heat it volatilizes. The porous salt absorbs water from the air, and dissolves in water very readily with evolution of heat; its maximum solubility is at temperatures between 33° C., 91° F., and 70° C., 158° F. It is used in the manufacture of glass, and in the preparation of caustic soda, which is used in the manufacture of soap. Sodium carbonate has the property of oxidizing many metals, such as tin, iron, zinc, etc., by the action of its carbonic acid, and as a consequence of this action it acts as a desulphurizer. It forms fusible compounds with silica and many metallic oxides; it also melts at a moderate temperature, absorbing many infusible substances, such as lime, alumina, charcoal, etc. In some cases it acts as a reducing agent, as in the case of chloride of silver. When mixed with carbonate of potash a double salt is formed, which fuses at a lower temperature than either taken alone, a property very useful in the fusion of silicate, etc. (Hiorns.)

Sodium chloride, NaCl, or common salt, occurs in nature in a nearly pure state. Rock salt has a specific gravity of 2.35. Weight per cubic foot, 147 pounds, or 0.084 pound per cubic inch. The solubility of pure salt in water is almost independent of temperature. Its melting point is 772° C., 1,421° F. It volatilizes at a red heat. Sodium chloride is the starting point in the preparation of all sodium compounds.

Sodium fluoride, NaF, occurs abundantly as cryolite, a so-called double fluoride of aluminium and sodium, represented by the formula $Na_3Al\,F_6$. Sodium fluoride crystallizes in colorless cubes, having a specific gravity of 2.766. Weight per cubic foot, 173 pounds, or 0.10 pound per cubic inch. It melts at about 900° C., 1,652° F., but volatilizes at a lower temperature.

Sodium amalgam is made by bringing sodium and mercury together. It is best prepared by adding successive small pieces of sodium to gently warmed mercury; as each piece dissolves it produces a flash of light and emits a hissing noise. With one part of sodium to 100 of mercury the amalgam formed has an oily consistency, but with 80 parts of mercury to one of sodium a pasty mass results, and with smaller ratios of mercury to sodium hard crystalline amalgams are obtained. This amalgam is used

in the preparation of other amalgams. Metallic chlorides, such as those of silver and gold, for example, are decomposed by sodium-amalgam, and the reduced metal then unites with the mercury. Metals which do not readily unite directly with mercury may be amalgamated by the action of sodium-amalgam on certain solutions of their salts. Thus: Iron-amalgam is obtained by immersing sodium-amalgam, containing 1% of sodium, in a clear saturated solution of ferrous sulphate. (Hiorns.) It is also used in the extraction of gold and silver from their ores instead of mercury. It is said to facilitate the amalgamation and to prevent "flouring" of the mercury; that is, it prevents the formation of oxide, sulphide, arsenide, etc., which would form a coat on the mercury and prevent contact with the gold or silver.

**Steel.**—Cast steel is of molten origin; it is distinguished from cast iron as containing less carbon, and in being malleable enough to be rolled into bars, shapes or plates, forged into shapes, or drawn into wire. It is distinguished from wrought iron in being homogeneous and not fibrous, and for its freedom from intermingled slag, which always accompanies wrought iron, due to the method of its manufacture by the puddling process. Steel welds readily and satisfactorily with wrought iron, less readily and less satisfactorily with steel. When alloyed with carbon, steel will harden upon quenching from a red heat, but steel may contain so little carbon as to be incapable of hardening by heating and quenching; this is true of the great mass of structural shapes and plates classed as mild steel.

**Steel Castings,** when of any considerable size, are commonly of open-hearth steel, which may be of any desired composition; inasmuch as they are made to take the place of forgings, the tensile strength of castings will approximate that of forgings perhaps higher. The tensile strength of castings for general purposes will vary from 60,000 to 75,000 pounds per square inch. The tensile strength of the steel suitable for locomotive frames is about 75,000 pounds as compared with 53,000 to 54,000 pounds per square inch for the best hammered iron. For warships the tensile strengths are graded from 60,000 to 80,000 pounds per square inch, with special castings of 90,000 pounds. The United States Navy castings contain 0.20 to 0.30% carbon. Steel castings shrink more than iron castings; the hotter the metal at time of pouring the greater the shrinkage. Patterns should have an allowance of about $\frac{1}{4}$ inch per foot for shrinkage. To stand the same stress as iron castings, steel castings need be but one-third to one-half as heavy, for medium thickness, such as heavy machine parts. Blow-holes can be prevented by the use of manganese and silicon, but in mild steel a small quantity of aluminium may be beneficial. Annealing is very important where the casting is subject to great strains or shocks, as it eliminates internal strains and tends to increase the ductility of the casting.

**Sulphur,** S.—Atomic weight, 31.98. Specific gravity, 2 = 125 pounds per cubic foot. Melting point, 114.5° C. (238° F.). Specific heat, 0.203. Latent heat, 17 B.t.u. Pure sulphur is a pale yellow brittle solid; it melts when heated, and distills over unaltered, if air be excluded. Sulphur is insoluble in water, and slightly soluble in alcohol and ether. Sulphur is a much less active element chemically than oxygen; it combines readily with most metals, forming compounds called *sulphides,* which are analogous to the oxides. Thus when heated together with iron, copper, or lead, combination takes place readily with evolution of heat. The only product of the combustion of sulphur in dry air or oxygen gas is *sulphur dioxide,* $SO_2$, or sulphurous oxide, a colorless gas, having the peculiar suffocating odor of burning brimstone; it instantly extinguishes flame, and is quite irrespirable.

**Tantalum,** Ta.—Atomic weight, 182. Specific gravity, 10.80. Melting point, 2,850° C. (5,160° F.). Specific heat, 0.036. Coefficient of linear expansion, 0.0000079. Electrical conductivity, 8.9, silver = 100. Tantalum occurs in the minerals columbite and tantalite, accompanied by niobium. In these minerals tantalum exists as a tantalate of iron and manganese. Metallic tantalum is obtained by heating the fluotantalate of potassium or sodium with metallic sodium in a well-covered iron crucible and washing out the soluble salts with water. It is a black powder, which, when heated in the air, burns with a bright light and is converted, though with difficulty, into tantalic oxide. Tantalum is used in steel making, but the utility of tantalum-steel alloys is as yet undetermined; at least its metallurgy may be said still to be in the experi-

mental stage. Iron alloyed with 5 to 10% tantalum is hard, but is ductile. Scientific investigators have experimented with a number of tantalum-steel alloys, but have thus far found them of no commercial value. It is thought that possibly had the steel contained a higher percentage of carbon more satisfactory results might have been obtained.

**Tin,** Sn.—Atomic weight, 119. Specific gravity, 7.29 = 455 pounds per cubic foot = 0.263 pound per cubic inch. Melting point, 231.9° C. (449.4° F.). Specific heat, 0.0551. Latent heat of fusion, 25.6 B.t.u. The boiling point has been variously placed: the Smithsonian Physical Tables give 1,450 to 1,600° C.; the "Metal Industry Handbook for 1916" gives 2,270° C. as a recent and reliable determination. Coefficient of linear expansion 0.0000209° C. and 0.0000116° F. temperatures. Heat conductivity 15.2, silver = 100.0. Electrical conductivity, 11.3, silver = 100.0. The tensile strength of tin is about 3,500 pounds per square inch; the crushing strength about 6,000 pounds per square inch.

Tin is a white metal not unlike silver in its general appearance. It is a soft metal, less hard than zinc, and harder than lead. It is malleable and ductile, but quite low in tenacity. Though seemingly amorphous, tin has a crystalline structure; when a bar or small ingot is bent or twisted it emits a characteristic crackling sound. This crystalline structure must account for the striking fact that the ingot, when exposed for a sufficient time to a very low temperature (to − 39° C. for 14 hours), becomes so brittle that it falls into powder under a pestle or hammer; it, indeed, sometimes crumbles into powder spontaneously. This behavior of the metal may probably be explained by assuming that in any tin crystal the coefficient of thermic expansion has one value in the direction of the principal axis and another in that of either of the subsidiary axes. From 0° to 100° C. the coefficients are practically identical; below − 14° C. and from somewhere considerably above 100° C. they assume different values and as the several crystals are differently oriented, this must tend to disintegrate the mass.

The ductility of tin under the hammer, at ordinary temperatures, is fairly good, the ductility seems to increase as the temperature rises up to about 100° C. (212° F.); above this temperature and near the fusing point (approximately 200° C.—392° F.) the metal becomes brittle, and still more brittle from − 14° C. (6.8° F.), downward. This property of brittleness is taken advantage of by heating ingots of tin to this critical temperature, and, dropping from a considerable height, the effect of the fall is to break up the ingot into small granular pieces which are marketed as grain-tin.*

Hydrochloric acid dissolves tin, forming stannous chloride, $SnCl_2$. When it is dissolved in sulphuric acid, stannous sulphate $SnSO_4$ is formed. Nitric acid oxidizes it, the product being a compound of tin, oxygen, and hydrogen known as metastannic acid; a white powder insoluble in nitric acid and in water. Tin does not form a compound with hydrogen.

As pure tin does not tarnish in the air and is proof against acid liquids, such as vinegar, lime juice, etc., it is utilized for culinary and domestic utensils. It is an expensive metal and vessels must be made heavy to give them stability of form; hence tin is generally employed merely as a protective coating for utensils made essentially of copper and iron.

Tinstone or cassiterite is the principal source of tin. The ores are roasted for getting rid of the sulphur and arsenic, the oxide is then heated with coal in a furnace and, after the reduction is complete, the tin is drawn off and cast in bars. This tin is impure and, when again slowly melted, that which first melts is purer. The commercial variety of tin known as *Banca* tin is the purest. It receives its name from Banca, in the East Indies, where it is made. *Block tin* is made in England and is also comparatively pure.

Tin is very largely used for coating iron, and special sheets of iron are manufactured for tinning and termed tinplate. The iron plates, having been carefully cleaned with sand and muriatic or sulphuric acid, and lastly with water, are plunged into heated

* When heated above its melting point, tin oxidizes rapidly, becoming converted into a whitish powder, used in the arts for polishing under the name of putty powder.

tallow to drive away the water without oxidation of the metal. They are next steeped in a bath, first of molten ferruginous, then of pure tin. They are then taken out and kept suspended in hot tallow to enable the surplus tin to run off. The tin of the second bath dissolves iron gradually and becomes fit for the first bath.

To tin cast-iron articles they must be decarburetted superficially by ignition within a bath of ferric oxide (powdered hematite or similar material), then cleaned with acid, and tinned by immersion as explained above.

By far the greater part of the tin produced metallurgically is used for making tin alloys.

**Titanium,** Ti.—Atomic weight, 48.1. Specific gravity, 4.8. Weight per cubic foot, 300 pounds or 0.17 pound per cubic inch. Melting point, 1,800° to 1,850° C. (3,272° to 3,362° F.). Specific heat, 0.130. Silver-white color, hard and brittle when cold, but can be readily forged when red hot.

Titanium is not found in a free state, but occurs as oxide in three minerals of different crystalline form, rutile, anatase, and brookite. Rutile occurs as a black or reddish-brown mineral having a specific gravity of about 4.3, and containing 98 to 99% of titanic oxide, $TiO_2$, together with 1 to 2% ferric oxide, $Fe_2O_3$. Ilmenite, or titaniferous iron ore, is an iron-black mineral having a specific gravity of about 4.5 and containing a maximum of 52.7% titanic oxide, and 47.3% ferrous oxide, corresponding to a formula FeO, $TiO_2$.

Ferro Alloys: One of the most important uses of titanium minerals is for the production of ferro alloys, which are used in the final purification of steel and cast iron. For the industrial production of ferro-titanium, two general processes are in use, one in which the finely pulverized titaniferous iron ore is mixed with charcoal and heated in an electric furnace of the Siemens type to a temperature of not less than 1,927° C. (3,500° F.). This yields an alloy containing 15 to 18% titanium, 5 to 8% carbon, and the balance iron. In the second type of process, if an alloy free from carbon is desired, the reduction is performed by some substance other than carbon, and for this purpose aluminium is frequently employed.

Ferro-titanium. The efficiency of ferro-titanium as a purifying agent is said to be due to the great affinity which titanium has for nitrogen and oxygen at temperatures above 800° C. (1,472° F.). Nitrogen in steel tends to cause brittleness and segregation of sulphur and phosphorus in the finished product. Titanium is not added to steel to give the latter new properties, but only as a cleanser, and in the finished steel practically no titanium remains. The alloy which finds most frequent use for this purpose is one containing 15 to 18% titanium. For low carbon steels, such as for wire or plate, from 2 to 4 pounds ferro-carbon titanium is used per ton of steel, for rail steel 15 to 20 pounds per ton is used. From 4 to 8 pounds of the alloy is added to each ton of steel castings. From 8 to 10 pounds per ton is used for axle steels.

Metallic titanium, other than in the form of its ferro alloys, has, so far, been put to but few uses. When heated to 600° C. (1,112° F.) in oxygen it readily burns to the oxide $TiO_2$, as it also does in nitrogen at 800° C. (1,472° F.), yielding in the latter case several nitrides, and this property has been suggested as a means of fixation of atmospheric nitrogen, as the nitrides are stated to yield ammonia on treatment with steam or acids. Titanium carbide produced in the electric furnace was used for the production of incandescent electric lamp filaments, but is now displaced by the more economical filaments, tantalum and tungsten.

Pig iron sometimes contains titanium, but as it is only reduced at very high temperatures it is usually found only in gray irons. Professor Turner mentions a sample of pig iron containing 0.28% titanium; it had a peculiar black mottled fracture characteristic of titanium, particularly at the bottom of the pig, and at the upper side there were blow holes. The titanium in this case was present probably as a carbide, and a carbide, TiC, has been isolated.

Titaniferous iron ores have been held in high esteem because the iron and steel produced was of excellent quality, but the excellence was probably due to the fact that such ores contain little or no phosphorus. Titanium is most abundant in gray pig irons, seldom in white irons, and none at all in puddled irons, as the titanium passes into the slag during the process of refining.

**Tungsten,** W.—Atomic weight, 184.0. Specific gravity, 19.10. Specific heat, 0.034. Melting point, 3,000° C. (5,430° F.). Specific heat, 0.034. Tungsten is found as a tungstate of iron and manganese in wolframite, $FeWO_4$, as tungstate of calcium, $CaWO_4$, and also as tungstate of lead, $PbWO_4$.

Tungsten is obtained in the state of a lustrous dark-gray powder or as a black powder by heating tungstic oxide in a stream of hydrogen, but for fusion an exceedingly high temperature is required. Heated to redness in the air, it takes fire and reproduces tungstic oxide. Tungsten forms three oxides, $WO_2$, $WO_3$, and $W_2O_5$, neither of which exhibits basic properties, so that there are no tungsten salts in which the metal replaces the hydrogen of an acid or takes the electro-positive part. The trioxide exhibits decided acid tendencies, uniting with basic metallic oxides and forming crystallizable salts called tungstates. The pentoxide may be regarded as a compound of the other two.

In a very general way ductile tungsten is made as follows: The carefully purified tungsten trioxide is reduced to metallic tungsten by passing pure hydrogen over the heated oxide. The resulting metal is in a fine powder, which is squeezed under a hydraulic press into a stick strong enough to stand careful handling. This stick is then heated to a very high temperature in a fuel-using furnace and later further sintered by heating under an electric current. It is then hammered, rolled, or drawn into the forms desired.

Tungsten is favorably known as a filament of incandescent lamps. The great improvements in drawing tungsten wire, and further improvements in the size of globe and in other mechanical details that add efficiency, have made the tungsten lamp far superior to the carbon-filament lamp and the arc lamp; it is much superior to the tantalum lamp, which was the first good metallic-filament incandescent lamp.

Diamonds are said to be used for dies in drawing tungsten wire. At first it did not seem possible to drill small enough holes through the diamonds to make wire sufficiently fine for lamps of small candle power, but wire 0.0006 inch in diameter can now be drawn in quantity.

The properties of pure wrought tungsten are entirely different from those of the powdered or ordinary cast metal. It is white, lustrous, tough and non-magnetic, and can be rolled, like steel, into a thin sheet, welded at a yellow heat, and drawn into a wire considerably thinner than 0.001 inch.

Hard-drawn tungsten wire has an electrical resistivity of 6.2 michroms per cubic centimeter at 25° C., the temperature coefficient for 0° C. to 170° C. being 0.0051. The corresponding figure for annealed wire is 5.0. Tungsten is unaffected by water or air at ordinary temperature, but both air and steam oxidize it at a red heat. Molten sulphur or phosphorus attacks it slowly, while at a red heat their vapors rapidly convert it into the sulphide or phosphide. It does not combine directly with nitrogen. Tungsten is one of the most important metals other than those commonly spoken of as commercial metals; the saving which has been introduced by its employment in steel manufacture and in the electric-light industry shows very remarkable figures. The patents of Mushet (1859) for the manufacture of steel, etc., containing tungsten, following a patent by Oxland (1857) for the production of certain alloys of tungsten with iron and steel, nickel, etc., and the earlier and more important patent of Oxland (1847) for the manufacture of sodium tungstate, tungstic acid, and metallic tungsten from tin-wolfram ores, may be considered to form the basis of all present commercial methods of treating tungsten ores and of practically all the technical uses of the metal and its compounds.

Ferro-tungsten is now being made by direct reduction of the ore in the electric furnace; the old difficulty, due to the large proportion of carbon formerly always present in directly made ferro-tungsten, has been largely overcome, but metallic tungsten and its alloys are still mainly prepared by the reduction of tungstic acid prepared from sodium tungstate, which has been obtained by fusion of wolfram with sodium carbonate.

**Vanadium,** V.—Atomic weight, 51.1. Specific gravity, 5.5. Melting point, 1730° C. (3150° F.). Specific heat, 0.125. It is grayish white in appearance, is non-magnetic,

has a high electrical resistivity, it is the hardest of the metallic elements and the most difficult to reduce. It has not yet been produced in the pure metallic state.

Vanadium alloys readily with iron, silicon, copper, nickel, and manganese, producing alloys with a relatively low melting point.

Vanadium acts on steel in the same manner as carbon, but to a much more decided extent, so that the carbon content must be carefully controlled. Arnold considers that vanadium combines with carbon to form a double carbide of iron and vanadium.

Vanadium seems to promote the even distribution of carbon and retards segregation, hence it largely prevents the deterioration of steel under constant vibration and its liability to brittleness. The only vanadium steels capable of application are those with less than 0.7% of vanadium.

The function of vanadium is to harden steel, increase its tenacity and elastic limit, without greatly lowering its elongation and reduction of area.

Vanadium steels are very sensitive to thermal and mechanical treatment and should not be used until they have been annealed at 900° C. and slowly cooled.—*Hiorns.*

The alloy of vanadium and iron is known as ferro-vanadium and when properly made with a content of from 30% to 40% vanadium and as little carbon as possible melts and dissolves readily at a temperature considerably below the fusing point of iron or steel.

The strong affinity of vanadium for carbon makes it impossible to produce ferro-vanadium with carbon as a reducing agent without obtaining a large percentage in the finished alloy. Ferro-vanadium reduced in this manner generally contains from 6% to 7% of carbon, an amount sufficient to combine with from 25% to 30% of vanadium.

Carbide of vanadium is a very stable compound, decomposed or broken up with difficulty. Added to molten steel, it goes into solution without decomposition and becomes practically an inert constituent. For this reason a ferro-vanadium containing any considerable amount of carbon will not produce the reaction combinations and physical results, when added to molten steel, that are obtained from ferro-vanadium containing little or no carbon, because the vanadium is not available to react with the other constituents of the steel. It is therefore necessary to reduce the vanadium by a process that will give a ferro-vanadium as free as possible from carbon.

Alloys of vanadium and iron can be made without great difficulty by reducing agents other than carbon and, by means of these, ferro-vanadium practically free from carbon can be produced.

The greater the degree of fusibility and solubility possessed by the ferro-vanadium, the more satisfactorily it should react when added to steel, other things being equal.

The melting point of a ferro-vanadium containing practically nothing besides vanadium and iron is about 1480° C. for a 40% alloy. The melting point gradually lowers with decreasing percentage of vanadium until 35% is reached, when the point remains practically constant at 1425° C. until 30% is reached, when the melting point again rises, and reaches about 1450° C. for a 25% alloy.

The presence of some of the other elements in the alloy, especially such as silicon and manganese, besides in other ways being beneficial, has a marked effect in lowering the melting point.

It is Professor Arnold's opinion that vanadium is undoubtedly the element which, together with carbon, acts with the greatest intensity in the way of improving alloys of iron, that is to say, in very small percentages. He was of the opinion that vanadium combines to form a double carbide of iron and vanadium, and that it has not only a chemical but a physical influence in promoting the even distribution of the carbon and retarding constitutional segregation. In this manner it renders steel particularly susceptible to the highly important improvement due to heat treatment, and, in addition, is a powerful factor in the production of steels that are very resistant to wear, erosion, and fatigue.

Vanadium is the most powerful metal yet discovered for alloying with steel. Its intensifying effect on the other elements generally used in the alloys, chromium, nickel, silicon, tungsten, and molybdenum, and even carbon, is so great, that although these elements preponderate the alloy is improved and changed to such a degree that it is designated as chrome-vanadium steel, nickel-vanadium steel, etc.

**Wulfenite.**—A mineral consisting of lead molybdate, $PbMoO_4$, crystallizing in the tetragonal system, and isomorphous with scheelite. Next to molybdenite it is the most abundant of the few minerals containing molybdenum. It has been found in some quantity at Bleiberg in Carinthia, and at several places in Arizona, Nevada and Utah. To obtain ferro-molybdenum of low carbon content, the wulfenite is smelted in the electric furnace with suitable quantities of coke and magnesium carbonate, the lead which is liberated being collected. The magnesian slag is pulverized and treated with boiling water, and the solution cooled, whereupon it deposits crystals of magnesium molybdate. These are dehydrated by calcination, powdered, mixed with the requisite amount of 50% ferro-silicon, and briquetted by means of tar or pitch. When these briquettes are heated in a furnace, the following reaction occurs:

$$4MgMoO_4 + 3FeSi_2 = Mo_4Fe_3 + 4MgSiO_3 + 2SiO_2.$$

If the magnesium molybdate is heated with molybdenum silicide, pure molybdenum is obtained.

**Zinc, Zn.**—Atomic weight, 65.2. Specific gravity, 7.15. Weight per cubic foot, 446.16 pounds = 0.258 pound per cubic inch. The specific gravity of zinc is not constant; that of pure ingot is 6.915, and rises to 7.191 after rolling. Melting point, 419.4° C. (786.9° F.). Boiling point, 906° C. (1663° F.). Specific heat, 0.094. The coefficient of linear expansion is .00002918 between 0 and 100° C.

Metallic zinc is not met with in nature; the ores of zinc from which the metal is extracted are: Red zinc ore, an impure oxide, $ZnO$; Calamine, a native carbonate, $ZnCO_3$, and Blende, a zinc sulphide, $ZnS$. The ore is first roasted to expel water and carbonic acid, then mixed with fragments of coke or charcoal, and distilled at a full red heat in a large earthen retort; carbon monoxide escapes, while the reduced metal volatilizes and is condensed by suitable means, generally with one or more impurities. Of the several metallic impurities in zinc ores, iron is at once the most common and the least objectionable, because it is absolutely non-volatile at the temperature of a zinc retort. As indicated, the zinc thus obtained is not pure but contains lead, iron, and sometimes arsenic and cadmium. This crude metal is called *spelter*.

Regarding the impurities, zinc made from oxidized ores is usually free from arsenic; that derived from blende is almost sure to contain it. Traces of arsenic do not, however, interfere with any of the technical applications of the metal. Cadmium and arsenic, being more volatile than zinc itself, if present, accumulate in the first fractions of the distillate, but may pervade it in traces to the end.

Zinc is a bluish-white metal, which slowly tarnishes in the air; it has a lamellar, crystalline structure, and is, under ordinary circumstances, brittle. Between 120° C. (248° F.) and 150° C. (300° F.) it is, on the contrary, malleable, and may be rolled or hammered without danger of fracture; and, what is very remarkable, after such treatment it retains its malleability when cold; the sheet zinc of commerce is thus made. At 210° C. (410° F.) it is so brittle that it may be reduced to powder. At 412° C. (773° F.) it melts; at a bright red heat it boils and volatilizes, and, if air be admitted, burns with a splendid greenish light, generating the oxide. Dilute acid dissolves zinc very readily, it is constantly employed in this manner for preparing hydrogen gas. Zinc forms with other metals a most important class of alloys, the chief being with copper to make brass; it is also used in the composition of white metals, German silver, etc. It is used in the form of sheets worked into a variety of shapes; it is used as a coating to protect iron from rusting, as in galvanized iron; it forms the electro-positive element in many batteries; and in the form of fine dust it is obtained in large quantities mixed with zinc oxide, and forms a valuable reducing agent.

The tensile strength of castings is about 5,600 pounds per square inch. The tensile strength of sheet zinc is about 17,920 pounds per square inch.

Zinc is a poor conductor of heat and electricity, its heat conductivity being about 26 and its electrical conductivity 25.5, silver being taken as 100 in each case.

Zinc is dissolved by vegetable acids; this metal should not, therefore, be used for cooking utensils.

# ALLOY STEELS

## BUREAU OF MINES

"Manufacture and Uses of Alloy Steels," by Henry D. Hibbard, prepared for the Bureau of Mines, gives briefly information of present value relating to the manufacture and uses of various commercial alloy steels, with the hope of stimulating the demand for such steels and extending their practical use. The following abstract is limited to the physical properties and uses of alloy steels.

### DEFINITIONS OF TERMS RELATING TO ALLOY STEELS

**Simple Steel,** often called "carbon steel," consists chiefly of iron, carbon, and manganese. Other elements are always present, but are not essential to the formation of the steel, and the content of carbon or manganese, or both, may be very small.

**Alloy Steel** is steel that contains one or more elements other than carbon in sufficient proportion to modify or improve substantially and positively some of its useful properties.

**Simple Alloy Steel** is alloy steel containing one alloying element, as for example, simple nickel steel.

**Ternary Steel** is alloy steel that contains one alloying element, the term being synonymous with "simple alloy steel."

**Quaternary Steel** is an alloy steel that contains two alloying elements, such as chromium-vanadium steel.

**Complex Steel** is an alloy steel containing more than two alloying elements, such as high-speed tool steel.

**Alloy-Treated Steel** is a simple steel to which one or more alloying elements have been added for curative purposes, but in which the excess of the element or elements is not enough to make it an alloy steel.

**Raw Steel** is steel as cast, either an ingot or casting.

**Natural Steel** is steel in the condition left by a hot-working operation, and cooled in the open air.

**Normalized Steel** is steel that has been given a normalizing heat treatment intended to bring all of a lot of samples under consideration into the same condition.

**Annealed Steel** is steel that has been subjected to an annealing operation.

**Hardened Steel** is steel that has been hardened by quenching from or above the hardening temperature.

**Tempered Steel** is steel that has been hardened and subsequently tempered by a second lower heating.

These definitions are based on the definition of steel that states that steel must be usefully malleable. The definitions of alloy steels do not include effects which are negative, or the prevention or cure of ills which the steel might possess were the alloying element or elements not added.

An iron alloy is not considered as useful unless it presents some useful property or modification of a property not offered to the same degree by a simple steel.

**Useful Alloy Steels.**—The eight alloy steels named below in the chronological order of their introduction include all the regular commercial varieties:

1. Simple tungsten steels
2. Simple chromium steels
3. Manganese steels
4. Simple nickel steels
5. Nickel-chromium steels
6. Silicon steels
7. High-speed tool steels
8. Chromium-vanadium steels

The first four and the sixth of these are ternary steels, the fifth and eighth are quaternary, and the seventh is of complex composition. Alloy steels are considered as regards their value for structural, cutting, or electrical purposes.

Steel used for structural purposes is taken to include that used for the stationary as well as the moving parts of structures and machines. Steel used for cutting purposes includes that employed to form an actual cutting edge and that used in projectiles for war. Steel for electrical purposes is used in magnets, core steel, non-magnetic articles, and electrical-resistance devices.

## SIMPLE TUNGSTEN STEEL

Mushet's air-hardening steel (1868), the first of the alloy steels, may be considered as a simple tungsten steel though it contained so much manganese (about 2%) that it might with some reason be classed as a quaternary steel, as it contained also about 2% of carbon and 6% of tungsten. The manganese was essential to give the self-hardening property.

Tungsten is very heavy, its specific gravity being, according to recent determinations, about 19.3, and it is the most infusible substance known except carbon and, perhaps, boron. These properties have some effect on the production of tungsten steel.

Tungsten steel is generally, if not always, made by the crucible process. Good tungsten steel makes remarkably sound solid ingots, except for the pipe, though tungsten itself is not considered to aid in removing or controlling either the oxides or the gases. It is added solely for its effect on the finished and treated steel.

Simple tun sten steel is at present chiefly used in permanent magnets for electric meters, in small dynamos, and hand use. This steel contains about 0.6% of carbon and 6% of tungsten.

To make permanent magnets retain their magnetism as much as possible they are made very hard by heating and quenching. They are then magnetized, and if they are to be used for electric meters, they are seasoned by a treatment involving protracted heating to 100° C. (212° F.) to make their magnetism as nearly constant as possible.

## SIMPLE CHROMIUM STEEL

Simple chromium steels, though one of the earliest if not the first of the alloy steels to be made, are not now largely used. In combination with other alloying elements, however, chromium is still one of the most important constituents of alloy steels. It is made by either the acid open-hearth or crucible process.

The effect of a chromium content up to a maximum of 2½% in steel is to increase the hardness moderately when the steel is in the natural state, and particularly when it is in the hardened condition after having been quenched.

Chromium steels are cast, forged, and rolled by the same methods as simple steels of the same or slightly higher carbon contents. Castings are annealed, or heat

Composition and Properties of Heat-Treated Simple Chromium Steels

| Sample No. | Constituents | | | | | | Tensile Strength | Elastic Limit | Contraction of Area | Elongation in 2 Inches | Ball hardness | Heat Treatment | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Mn | Si | S | P | Cr | | | | | | Temperature at Which Steel Was Quenched in Water | Temperature at Which Hardness Was Drawn in Air |
| | % | % | % | % | % | % | Lbs. | Lbs. | % | % | | °C. | °C. |
| 1..... | 0.70 | 0.54 | 0.09 | 0.01 | 0.01 | 0.70 | 129,000 | 121,700 | 60 | 21 | 235 | 816 | 593 |
| 2..... | .70 | .54 | .09 | .01 | .01 | .70 | 110,900 | 105,300 | 63 | 26 | 195 | 816 | 649 |
| 3..... | .70 | .54 | .09 | .01 | .01 | .70 | 88,000 | 73,000 | 68 | 36 | 168 | 816 | 754 |
| 4..... | .40 | .78 | .54 | .02 | .01 | .92 | 143,500 | 131,600 | 56 | 18 | 242 | 816 | 538 |
| 5..... | .40 | .78 | .54 | .02 | .01 | .92 | 103,200 | 90,200 | 69 | 26 | 201 | 816 | 714 |
| 6..... | .91 | .35 | .08 | .03 | .01 | .91 | 96,800 | 69,300 | 63 | 28 | 175 | ...... | ...... |

treated, as the conditions warrant or require to give the most suitable properties for the proposed use.

Chromium steels are perhaps never used in the untreated condition, and their properties in that state are therefore not given.

The longest established use of chromium steels now current is in stamp shoes and dies for pulverizing certain gold and silver ores. These shoes and dies contain 0.8 to 0.9% of carbon, with 0.4 to 0.5% of chromium. They are preferably annealed to destroy ingotism and so impart some toughness to the metal, which increases their durability in an important degree.

Another long-established use of chromium steel is in five-ply plates for the manufacture of safes. These plates are made of five alternate layers, two of chromium steel and three of soft steel or wrought iron, and after having been hardened offer great resistance to the drilling tools employed by burglars.

Hardened chromium-steel rolls having 0.9% of carbon and 2% of chromium are used for cold-rolling metals. They are glass hard so that the ball hardness can not be determined, the ball making no impression. The hardness, as determined by the sclerescope, is 107.

Files of chromium steel are excellent, the carbon content being 1.3 to 1.5% and the chromium content about 0.5%.

An important use of chromium steel is in balls and rollers for bearings. One large maker uses steel containing carbon, 1.10%; chromium, 1.40%; manganese, 0.35%; sulphur, 0.025%; and phosphorus, 0.025%. Sizes smaller than one-half inch diameter are heat-treated by being quenched in water from 774° C. (1,425° F.) and then drawn to 190° C. (375° F.) for half an hour. For larger balls the quenching temperature is 802° C. (1,475° F.). The second heating does not produce an oxide color, but is enough to let down in some degree the internal stresses due to the irregular cooling of quenching so that the balls are less liable to crack spontaneously or to be broken in use.

The strength of a good, well-treated ball is prodigious, a ball three-fourths of an inch diameter, tested by the three-ball method, sustaining a load of 52,000 pounds. On the small area of contact the intensity of the pressure amounts to over one million pounds per square inch.

## MANGANESE STEEL

Manganese steel in the commercial meaning of the name is a variety of iron containing 11 to 14% of manganese and 1.0 to 1.3% of carbon. The bulk of the manganese steel made at present is put into castings.

**Manufacture.**—Manganese steel is still made in the ladle according to Hadfield's expired patents by the mixture of decarburized iron and 80% ferromanganese. The decarburized iron is prepared either by the pneumatic process, being blown in some one of the many modified pneumatic converters or in the Siemens furnace. As ferromanganese forms such a large proportion of the charge, about one-seventh, it must be melted or nearly so before being added to or mixed with the decarburized iron, or the resulting steel would be too cold. After the manganese steel has been made in the ladle it should be cast as soon as practicable if it is to be used for castings, but if it is to be used for ingots a little time should be allowed for the silicate formed within the metal to collect and float to the top.

The quantity of manganese is proportioned to the size of the charge of decarburized iron with allowance for loss through oxidation of an amount equal to about 1½% of the steel. Thus 14% is added to yield 12.5% in the steel.

Because of its large content of carbon, silicon, and manganese, the latter fusing at 1,260° C., manganese steel melts at about 1,325° C., a temperature lower than that of simple steel, and one that favors the running of intricate castings. For the same reason manganese steel, containing so much gas solvent, is usually free from gas holes; but if the decarburized iron of which it is made is too hot, and therefore too heavily charged with gases, the solvent powers of the silicon and manganese may be exceeded and the steel be saturated with gases, the ingots or castings being consequently infested with blowholes by the gases liberated in cooling.

**Composition.**—In making manganese steel one composition is practically standard. The usual analyses of manganese steel lie between the following limits: Carbon, 1.0 to 1.3%; silicon, 0.3 to 0.8%; manganese, 11.0 to 14.0%; phosphorus, 0.05 to 0.08%. The sulphur content is so low as to be negligible in manganese steel as in other iron-manganese alloys, from which any sulphur that may get in is quickly eliminated by the manganese, probably as sulphide, which rises to the surface or enters the slag.

Low-manganese steels with 7 to 8% of manganese are finding some use, having a higher and better defined elastic limit than the regular grade and yet with considerable though much less ductility. Manganese-iron alloys containing 3 to 10% of manganese and 1% of carbon are martensitic. With the manganese over 10% the structure is austenitic. The steels having 7 to 10% of manganese are so different from commercial manganese steel that another name should be given them to avoid confusion. The name "loman steel," an abbreviation of "low-manganese steel," has been applied to them and seems to be suitable as a short distinctive name.

**Properties.**—Manganese steel is a hard self-hardening steel, owing this property to its composition and not to treatment. It can not be softened by heating followed by slow cooling. It is, for a metal, a poor conductor of electricity.

Manganese steel has a high coefficient of expansion, small patterns being made with a shrinkage of five-sixteenths of an inch to 1 foot, which sometimes is not quite enough. A shrinkage of five-sixteenths of an inch to 1 foot gives a mean coefficient of expansion of about 0.000024 per degree Centigrade.

In respect to specific gravity, manganese steel is not to be distinguished from simple steels of the same carbon content, as all have, generally speaking, about the same.

Perhaps the most remarkable property of manganese steel is its almost total lack of magnetic permeability and susceptibility. This metal, containing 85% of iron in a metallic form, is so slightly attracted by a magnet that the pull can not be felt with the hand.

The properties of manganese steel in the raw state are much like those of other raw high-carbon steels, the metal being very hard, but its ductility being practically negligible. The steel, because non-magnetic, may be used for purposes requiring a hard non-magnetic metal, if it is not liable to shock.

**Heat Treatment.**—Although the composition of manganese steel is extremely important in determining its properties, the heat treatment to which it is subjected to develop in it its great toughness or ductility is even more so.

As used, it is almost universally water-toughened according to the method Hadfield set forth, which treatment consists in heating the whole article to about 1,050° C. and then cooling it as quickly as possible by immersing it in cold water, the colder the water and the more of it the better. It will not do to heat only a part of the piece for quenching, and if a part of a toughened article becomes heated to redness or near it by accident or design the whole piece should be reheated and again quenched to give it proper qualities for use. No time should be lost in completing the heating and quenching after the piece has become red-hot to avoid oxidation as completely as possible.

Manganese steel is a poor conductor of heat, a factor that interferes with its heat treatment and tends to limit the thickness of the steel that may be profitably treated. This limit of thickness is generally taken as 4 inches, though somewhat thicker pieces in which the presence of internal cracks in the central parts would not be ruinous are treated in particular instances.

**The hardness** of toughened manganese steel is unique, and it may be termed a tough hardness and not a flinty hardness. Such steel may easily be dented with a hammer or marked with a file or chisel, but cutting it to a useful extent is almost impracticable, so that such finishing as is necessary is usually done by grinding with abrasive wheels.

**The water toughening** of manganese steel gives it great ductility—greater as to elongation, perhaps, than that of any other steel and exceeding sometimes 50% in 8 inches, although its high degree of hardness is not greatly altered. This high ductility in combination with the great hardness of manganese steel gives it great resistance to abrasive wear as well as safety from breakage. Practically all manganese steel is used in the toughened state.

**In the pulling test** the percentage of contraction of area is less than the elongation, a result directly opposite to that with simple as well as most alloy steels, in which the percentage of contraction is usually twice or more than of the elongation. The pulled test piece has a rather uniform stretch throughout its length, whereas simple steels, as is well known, have a largely increased amount of stretch near the point of fracture. A recent pulling test of forged, heat-treated manganese steel gave the results following. The steel was cast in a test bar 3 inches square, forged down to a test piece of about the dimensions given, and finished by grinding.

| | |
|---|---|
| Diameter of piece, inches | 0.823 |
| Length, inches | 2 |
| Tensile strength per square inch, pounds | 152,840 |
| Elastic limit per square inch, pounds | 56,400 |
| Elongation, per cent | 51 |
| Contraction, per cent | 39.5 |
| Carbon, per cent | 1.10 |
| Manganese, per cent | 12.4 |
| Silicon, per cent | 0.15 |
| Phosphorus, per cent | 0.06 |

The length of the pulled section of a manganese-steel test piece does not affect the elongation as much as is the case with simple steels because the stretch is so much more nearly uniform, as described above.

**The elastic limit** of manganese steel is unexpectedly low and not well defined, as the steel yields at a gradually increasing rate when pulled, as in testing, giving no point that, strictly speaking, can be said to be the elastic limit or even yield point.

Owing to its lack of elastic limit and to its high ductility, manganese steel is prone to flow under stress, and it does not have high resistance to compression or to continually repeated blows of a hard mineral or other material that will gradually batter it out of shape.

COMPRESSION TESTS OF CAST MANGANESE STEEL

(*Watertown Arsenal*)

| Number of Test Piece | Analysis | | | | Permanent Set at a Pressure per Square Inch of— | | | | Total Load |
|---|---|---|---|---|---|---|---|---|---|
| | C. | Si. | Mn. | Cr. | 40,000 Pounds | 50,000 Pounds | 60,000 Pounds | 70,000 Pounds | |
| | % | % | % | % | Ins. | Ins. | Ins. | Ins. | Lbs. |
| 1 | 1.23 | 0.95 | 12.6 | .... | 0.0006 | 0.0036 | 0.0213 | 0.0981 | 190,100 |
| 2 | 1.26 | .54 | 12.8 | .... | .0020 | .0046 | .0182 | .0899 | 180,100 |
| 3 | 1.31 | .43 | 12.7 | .... | .0010 | .0036 | .0204 | .0998 | 172,300 |
| 4 | 1.22 | .72 | 11.7 | 0.86 | .0002 | .0009 | .0038 | .0220 | 175,200 |

All test pieces were cast and finished by grinding to 4 inches long and 1.129 inches in diameter, giving 1 square inch of cross-sectional area. At the total load the pieces buckled. The permanent set at a pressure of 40,000 pounds per square inch shows that the limit of elasticity was passed in every case.

The hardness by Brinell's ball test of manganese steel is low, running usually about 190.

**Manganese-steel Castings** are made in dry sand, in green sand, and in some instances in iron molds, the considerations leading to the adoption of any particular material being much the same as with ordinary simple steel castings, such as danger of pulling apart or cracking in cooling, misrunning, or failure to fill the mold properly, and breaking or washing of the mold, and numerous others. The high coefficient of

expansion of manganese steel must be considered, as it increases the liability of a casting to be cracked or pulled apart by shrinkage in cooling.

Manganese steel is prone to settle, as it solidifies, demanding, for a given massiveness of design, larger sink heads than simple steels to feed the casting properly and prevent settle holes.

Even more than with other steel castings, it is important that manganese-steel castings be so designed that the mass is fairly uniform throughout, or in particular that no part is much thicker than the rest. If a thick part is unavoidable, it should be connected with a sink head by metal as thick or nearly so. Thus, bosses and heavy fillets, often advisable in iron and simple steel castings, should be avoided because of the local increase of the mass they cause. The trouble is that a heavy part incompletely fed will be unsound in its central parts. A hole or recess cored in, if permissible, may prevent the central cavity, or an iron or soft steel core may be imbedded in the thick part, which, by hastening the solidification of the metal, may prevent the formation of holes or loose metal there.

**Uses.**—Manganese steel resists admirably abrasion under slow speeds of impact, as in Blake crushers, rolls, gyratory crushers, and similar machines; but results in high-speed grinders, such as the various centrifugal mills, are, if not poor, at least such as will not often warrant the expense of manganese-steel wearing parts, especially if such parts require some finishing, which must be done by slow and expensive grinding.

For railway-track work, manganese-steel cast frogs, switches, curved rails, and other special work are most excellent, and they are extensively used.

The properties of the metal were early seen to make it an ideal material of which to make burglar-proof safes and vaults; that is, it is too hard to be cut and too strong to be broken even by considerable charges of dynamite and nitroglycerin.

The non-magnetic property of manganese steel has found an important use in the cover plates of lifting magnets for handling heavy iron and steel articles where it is subjected to hard blows from the pieces jumping to meet the magnets. It offers little or no obstruction to the passage of the magnetic attraction. It is also used in the structure about the compasses on some ships because it does not affect the compass needle.

**Hot Working.**—Manganese steel is, like simple steel, or even more so, improved in its physical properties by forging or rolling. Cast test pieces usually give misleading results because of imperfections due to casting. A steel that, cast and heat-treated, may show a tensile strength of 80,000 pounds per square inch with 20% elongation may have, when well worked by forging and rolling and then heat treated, a tensile strength of 140,000 pounds per square inch and 50% of elongation in 8 inches.

Cold working, such as stretching or cold rolling, rapidly raises its tensile strength and elastic limit but destroys most of its ductility. Cold-rolled manganese steel on test has shown a tensile strength of 250,000 pounds per square inch and an elastic limit of 230,000 pounds.

The largest demand for hot-worked manganese steel is in rails for railroads. The rails are rolled on ordinary rail mills and are heat treated by being quenched immediately after rolling. The service rendered by the rails is excellent and their use is extending. Some railroad men think their durability at least five times that of ordinary rails.

## SIMPLE NICKEL STEELS

Nickel steel was chronologically the fourth alloy steel to be introduced; the useful nickel-iron alloys range, with large intervals, from 2 to 46% of nickel, a greater compass than is covered by any other element alloyed with iron.

Nickel in untreated ordinary nickel steel raises the tensile strength and, in a greater proportion, the elastic limit for a given content of carbon without decreasing the ductility.

Nickel steels with the different percentages of nickel present about the same range of internal microscopic structures as do manganese-iron alloys. With low nickel content, as in the great bulk of nickel steels made, the unhardened steel is pearlitic. Higher nickel content gives martensitic structure, and still higher austenitic.

**Manufacture.**—Nickel steel is made by any of the steel-making processes, but most of it is produced in the open-hearth furnace. The operations are similar to those followed in the production of simple steels, the nickel being either in the materials of the original charge or added in the metallic form at any time long enough before the heat is cast for the nickel to be melted and thoroughly mixed with the metal of the charge. Nickel is negative to iron at steel-melting temperatures, and the iron protects it from oxidation and even reduces it from its oxide, so that it is not wasted to any considerable extent in melting or working even when iron ore is added to the bath. On the other hand, it does not deoxidize the metal or decompose carbonic oxide or keep the hydrogen and other gases in solution. It is not added, therefore, for curative purposes, as it gives no aid in rendering steel sound or free from holes. In fact, nickel steel is prone to have seams and surface defects after it has been rolled, which is one reason against its wider use. The service of nickel is merely as an alloying element, to improve the physical properties of the finished steel either in its natural or heat-treated condition.

**Hot Working.**—Ordinary simple nickel steel (3 to 4% nickel) is worked hot by the usual forging and rolling operations much as simple steel is worked. The higher nickel steels are more difficult to work, having narrower ranges of temperature at which they may be hot-worked without showing signs of redshortness.

Although molten iron protects molten nickel from oxidation, iron can not protect nickel from oxidation in scale formed on nickel steel, as in the heating furnace. The scale formed sticks much more firmly to the metal than that of simple steel, both hot and cold, and requires particular measures for its removal.

Steels containing useful quantities of nickel are liable to contain seams that appear as dark-colored lines in the metal. The seams doubtless come, sometimes at least, from "skin" gas holes which become oxidized on their walls. It is held by some persons that seams develop in rolling without being caused by gas holes, and that this tendency is lessened by rolling at a high temperature, about 1,300° C. (2,372° F.).

**Structural Steel.**—The great bulk of simple nickel steels contains from 2 to 4% of nickel, a proportion that affords the most suitable physical properties for nearly all structural purposes, and the nickel content usually aimed at in steels for structural purposes is 3.25%. This grade might be called ordinary nickel steel, as it is usually meant when nickel steel is mentioned without further specification. It has high value for structural purposes such as bridges, gun forgings, machine parts, engine and automobile parts, and any similar line of service that is too severe for simple steels.

Steel with 2% of nickel is used in seamless tubes such as are used for bicycles. They are not heat treated, but higher properties than those of the steel in its natural state are imparted by the cold-drawing operations by which these tubes are finished. The ordinary grade with 3.5% nickel is used in cannon, being always heat treated for this use. It is also used in many automobile parts, the variety of high properties obtainable in it by modifying its heat treatment rendering it fit for almost any service demanding a strength and security from breakage that a simple steel will not meet.

In some large dynamos the revolving fields are connected by nickel-steel rings having 3% nickel, the metal being particularly well suited for the purpose both by its strength and its magnetic efficiency, the permeability being high and the hysteresis losses low.

## PROPERTIES OF ORDINARY NICKEL STEEL

All the samples consisted of small test pieces, and elongations were measured on 2 inches except as noted.

One per cent of nickel in ordinary nickel steel in the natural state raises the tensility about 6,000 to 8,000 pounds per square inch.

**Castings.**—The properties of one grade of nickel-steel castings made for special purposes are as follows: Composition, C 0.20%, Mn 0.50%, Si 0.35%, Ni 2.50%; tensile strength, 85,000 pounds per square inch; elongation, 25%; contraction, 40%. This steel was not given treatment involving quenching but was merely annealed.

**Arnold and Read's Alloy.**—The 13% nickel-iron alloy with 0.55% carbon discovered recently by Arnold and Read is noteworthy, as it seems to possess the highest

strength of any of the nickel steels. It is so hard as to be unmachinable, and investigators were not able to drill it even to get some drillings for analysis, the composition mentioned being what they aimed at when making the steel. It has a yield point of about 134,000 pounds per square inch, a tensile strength of about 195,000 pounds, with 12% of elongation in 2 inches.

Hadfield's experiments showed that low-carbon steels with 11.4 and 15.5% of nickel each had a tensility of 210,560 pounds, which was more than was possessed by the steels next above and below. The curve therefore should have reached a maximum between them with a nickel content of about 13.5%.

Arnold and Read's steel should, of course, have a higher tensility, or about 215,000 pounds, to harmonize with Hadfield's, and further tests are needed to establish the

| Sample No. | Composition | | | | | | Condition | Physical Properties | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Mn | Si | S | P | Ni | | Tensile Strength | Elastic Limit | Elongation | Contraction | Ball Hardness |
| | % | % | % | % | % | % | | Lbs. | Lbs. | % | % | |
| 1[a] | 0.28 | 0.57 | .... | 0.03 | 0.02 | 3.44 | Natural state... | 95,420 | 56,670 | [b]21.2 | 50 | .... |
| 2[c] | .40 | .64 | .... | .02 | .01 | 3.43 | Annealed...... | 98,800 | 51,400 | [d]12.4 | 33 | .... |
| 3[c] | .40 | .55 | .... | .03 | .01 | 3.70 | Annealed...... | 93,180 | 56,060 | [d]15.8 | 40 | .... |
| 4[e] | .20 | .65 | .... | .04 | .04 | 3.5 | Annealed...... | ...... | 43,000 | 27 | 62 | 170 |
| 5[e] | .20 | .65 | .... | .04 | .04 | 3.5 | [f] ............ | ...... | 95,000 | 20 | 72 | 216 |
| 6[e] | .20 | .65 | .... | .04 | .04 | 3.5 | [g] ............ | ...... | 140,000 | 14 | 61 | 330 |
| 7[e] | .30 | .65 | .... | .04 | .04 | 3.5 | Annealed...... | ...... | 63,000 | 27 | 63 | 163 |
| 8[e] | .30 | .65 | .... | .04 | .04 | 3.5 | [h] ............ | ...... | 87,000 | 25 | 68 | 207 |
| 9[e] | .30 | .65 | .... | .04 | .04 | 3.5 | [i] ............ | ...... | 123,000 | 15 | 57 | 269 |
| 10[e] | .30 | .65 | .... | .04 | .04 | 3.5 | [j] ............ | ...... | 187,000 | 13 | 57 | 405 |
| 11[k] | .25 | .74 | 0.21 | .01 | .01 | 3.55 | [l] ............ | 207,000 | 177,000 | 14 | 60 | 395 |
| 12[k] | .25 | .74 | .21 | .01 | .01 | 3.55 | [m] ............ | 135,000 | 117,000 | 20 | 67 | 267 |

*a* Sample represented untreated steel for Quebec bridge.
*b* In 8 inches.
*c* Full size eyebars for St. Louis Municipal Bridge.
*d* In 18 feet.
*e* Figures taken from Fourth report of Iron and Steel Division: Bull. Soc. Automobile Eng., vol. 4, 1913, p. 168.
*f* Quenched in water at 850° C.; hardness drawn in air at 538° C.
*g* Quenched in water at 800° C.; hardness drawn in air at 316° C.
*h* Quenched in water at 800° C.; hardness drawn in air at 593° C.
*i* Quenched in water at 800° C.; hardness drawn in air at 399° C.
*j* Quenched in water at 800° C.; hardness drawn in air at 316° C.
*k* Figures furnished by Halcomb Steel Co.
*l* Quenched in water at 843° C.; hardness drawn in air at 316° C.
*m* Quenched in water at 843° C.; hardness drawn in air at 538° C.

exact path of the curve. Arnold and Read note that the composition of this steel nearly corresponds with the formula $Fe_7Ni$.

**Properties of Nickel Steels.**—Before Arnold and Read's discovery of the 13% grade, 15% nickel steel was thought to have the greatest strength of all the nickel steels—that is, in the natural state. It is hard to machine, and heating followed by slow cooling does not soften it, though heating and quenching do enough to allow it to be machined slowly. It has a tensility of about 170,000 pounds and an elastic limit of 150,000 pounds per square inch, according to one observer, though, as stated above, Hadfield obtained 210,560 pounds tensility, with little ductility.

Eighteen per cent nickel-iron alloy, although not useful, is worthy of note here because of its anomalous action when cooled from 200° C. (392° F.). At first it contracts uniformly until its temperature falls to 130° C. (266° F.). Then it expands while cooling to 60° C. (140° F.), when it again contracts as the temperature falls farther.

Twenty-two per cent nickel steel is used when resistance to rusting or corrosion

is desired. It is also used sometimes for the spark poles in the spark plugs of internal-combustion engines, including automobiles, though commercial nickel wire is more commonly used.

High-nickel steels having 25% or more of nickel and low carbon content (about 3%) are austenitic in structure and in the natural state are softer and tougher than the medium-nickel martensitic steels.

Steels containing more than 24% of nickel are practically non-magnetic in their ordinary condition, a rather remarkable fact when the high magnetic susceptibility of both iron and nickel alone is considered. The explanation that the critical point marking the change from the non-magnetic to the magnetic state of iron is lowered by the nickel from about 700° C. (1,292° F.) to below ordinary atmospheric temperatures is, no doubt, sound as far as it goes. When 25% nickel steel is cooled to −40° C. (−40° F.) it becomes magnetic, and retains its magnetism at ordinary atmospheric temperatures. On being heated to 580° C. (1,076° F.), however, the alloy reverts to the non-magnetic state. This separation of 620° C. between the critical points marking the magnetic states in heating and cooling is great in comparison with the 25° to 50° C. of simple steels, and because of it this steel is classed as irreversible.

**Boiler Tubes.**—Nickel steel with 30% of nickel is used in boiler tubes, particularly in marine boilers, for which it is admirable. These tubes are in the natural, not heat-treated state. They resist corrosion better than simple steel tubes and last three times as long. Hence their use is sometimes economical in spite of the much higher cost.

**Invar.**—The 36% nickel steel known as invar is used to the extent of perhaps a few hundred pounds a year in clock pendulums, rods for measuring instruments, and such parts for which its exceedingly slight expansion and contraction when heated and cooled within the atmospheric range give it a particular value. Nevertheless, its coefficient of expansion, even though small, is not negligible, and compensating means must be used in invar clock pendulums and in the invar balance-wheels of watches.

Some invar has as low a coefficient of expansion as 0.0000008 per degree centigrade, and samples have been made that contracted slightly when warmed. The coefficient given indicates an expansion of 0.05 inch in a mile per degree C.

When invar is heated to about 300° C. (572° F.) and higher its coefficient of expansion is greatly increased and its lack of expansion at ordinary temperatures appears to be merely a belated and not destroyed function. With excessive cold there is likewise a resumption of contraction.

**Platinite.**—Forty-six per cent nickel steel with 0.15% carbon, known as platinite, has about the same coefficient of expansion as platinum and glass, and for that reason may be imbedded in glass without breaking the latter by a difference in expansion. It has been used in leading wires in the glass bases of electric incandescent lamp bulbs as a substitute for platinum, which was formerly held to be indispensable. In those lamp bulbs the preservation of the vacuum is necessary and the joint between the wire and glass must be kept tight. Platinite has not been found wholly suitable for this purpose, and is not now so used, a compound wire with a 38% nickel-steel core encased in copper and sometimes coated with platinum being now generally employed. The nickel-steel core if free will expand less than the glass and the copper more, so that each resists the other and the wire as a whole will have the desired rate of expansion.

## NICKEL-CHROMIUM STEELS

Nickel-chromium steels, known in the trade as chrome-nickel steels, are perhaps the most important of the structural alloy steels. Their field of usefulness is continually being enlarged by their application for new purposes and also by encroachment on the premises of some of the other alloy steels, notably of simple nickel steel, and they have almost wholly displaced nickel-vanadium and nickel-chromium-vanadium steels, which several years ago were in some considerable demand.

Nickel-chromium steels are seldom used in any but a heat-treated condition. By suitable treatment pieces of small mass can be made to have as high physical properties as any steels known, accompanied by ductility that is high as compared with its strength, as the ductility naturally lessens as the elastic limit increases.

# NICKEL-CHROMIUM STEEL

Nickel-chromium steels can be made somewhat more cheaply than simple nickel steel of the same strength and ductility containing a smaller total of the alloying elements, and chromium is less costly than nickel.

**Composition and Properties.**—The upper limit of nickel in useful chrome-nickel steels is about 3.5%, and all useful steels of this class are pearlitic. When a chrome-nickel steel is case-hardened, the case is harder than that of a simple nickel steel.

COMPOSITION AND PROPERTIES OF NICKEL-CHROMIUM STEELS IN NATURAL OR UNTREATED STATE

| Sample No. | Composition | | | | | | | Tensile Properties | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Mn | Si | S | P | Ni | Cr | Tensile Strength | Elastic Limit | Contraction of Area | Elongation in 2 Ins. | Ball hardness | |
| | % | % | % | % | % | % | % | Lbs. | Lbs. | % | % | | |
| 1..... | 0.55 | 0.41 | 0.22 | 0.03 | 0.02 | 1.53 | 1.14 | 96,000 | 75,000 | 66 | 31 | 185 | Annealed |
| 2..... | .18 | .27 | .05 | .04 | .02 | 1.28 | 1.59 | 72,000 | 51,000 | 71 | 37 | 134 | Annealed |
| 3..... | .15 | .34 | .13 | .02 | .01 | 1.28 | .37 | 59,000 | 42,000 | 64 | 38 | 115 | Annealed |
| 4..... | .29 | .42 | .07 | .06 | .02 | 3.86 | 1.48 | ...... | ...... | .... | .... | ..... | Natural |
| 5..... | .25 | .32 | .10 | .03 | .02 | 1.45 | 1.20 | 96,500 | 81,500 | 68 | 25 | ..... | Test piece |
| 6..... | .25 | .32 | .10 | .03 | .02 | 1.45 | 1.20 | 97,100 | 80,900 | 49 | [a] 7 | ..... | Eyebar; full size |

[a] In 21 feet.

Sample 4 is from a plate similar to that used in the mast of the yacht *Vanitie*. It was not heat treated, but was used as rolled.

Samples 5 and 6 represent the same steel and show the relative properties of the small test piece and the full-size eyebar for a bridge the section of which was 14 × 2 inches. The difference in elongation is particularly noticeable, the great local stretch near the point of rupture being only a small part of the total length of the bar.

COMPOSITION AND PROPERTIES OF NICKEL-CHROMIUM STEELS IN HEAT-TREATED CONDITION

| Sample No. | Composition | | | | | | | Tensile Properties | | | | | Heat Treatment | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Mn | Si | S | P | Ni | Cr | Tensility | Elastic Limit | Contraction of Area | Elongation in 2 Ins. | Ball hardness | Temperature at Which Steel Was Quenched in Water | Temperature at Which Temper Was Drawn in Air |
| | % | % | % | % | % | % | % | Lbs. | Lbs. | % | % | | °C. | °C. |
| 1.... | 0.40 | 0.74 | 0.24 | 0.03 | 0.02 | 3.45 | 1.20 | 187,000 | 175,000 | 43 | 10 | 352 | 830 | 371 |
| 2.... | .36 | .53 | .11 | .04 | .01 | 1.55 | .70 | 145,000 | 125,000 | 65 | 20 | 233 | 830 | 566 |
| 3.... | .21 | .41 | .22 | .03 | .02 | 3.52 | 1.11 | 110,000 | 75,000 | 66 | 24 | 215 | 830 | 682 |
| 4.... | .48 | .44 | .16 | .01 | .01 | 2.02 | .98 | 212,000 | 186,000 | 46 | 10 | 445 | 843 | 427 |
| 5.... | .48 | .44 | .16 | .01 | .01 | 2.02 | .98 | 140,000 | 120,000 | 61 | 18 | 287 | 843 | 649 |
| 6.... | .38 | .28 | .27 | .02 | .01 | 3.01 | .65 | 114,000 | 90,000 | 69 | 25 | 266 | 843 | 649 |

Any one of the first three samples could be given substantially the properties of either of the other two by varying the temperature of the second heating.

**For Automobiles**—and the practice might be advantageously extended to other fields—three grades of nickel-chromium steel are used. They are called low, medium, or high according to their contents of nickel and chromium. The carbon content may be varied for each grade within the limits shown in the following table:

COMPOSITION OF NICKEL-CHROMIUM AUTOMOBILE STEELS

| Grade | C | Mn | Si | S | P | Ni | Cr |
|---|---|---|---|---|---|---|---|
| Low... | 0.20 to 0.40 | 0.65 | Low | 0.045 | 0.04 | 1.25 | 0.6 |
| Med... | .20 to .40 | .65 | Low | .045 | .04 | 1.75 | 1.10 |
| High.. | .20 to .40 | .65 | Low | .045 | .04 | 3.50 | 1.50 |

These steels are almost invariably heat-treated for use in automobiles, a wide range of properties being attainable by varying the heat treatment with each steel. The properties overlap those of steels of both harder and softer grades, so that a wide choice of properties is afforded as well as a choice of steels for the set of properties desired.

**Armor Plate.**—An important use for chrome-nickel steel is in both thick and medium armor plate for war-vessels. The thick, heavy side armor, 6 to 14 inches thick, is face-hardened. A recent analysis of the body of a plate gave: C 0.33%, Mn 0.32%, Si 0.06%, S 0.03%, P 0.014%, Ni 4%, Cr 2%, and its tensile properties after treatment were:

| | |
|---|---|
| Tensile strength, pounds per square inch | 101,000 |
| Elastic limit, pounds per square inch | 77,500 |
| Elongation in 2 inches, per cent | 24 |
| Contraction of area, per cent | 60 |

The results from such a great mass of metal were excellent.

Medium armor, between 3 to 5 inches thick, is rather similar in composition. It is not face-hardened, but is given high properties as a whole by the heat treatment to which it is subjected. An analysis lately made gave: C 0.30%, Mn 0.34%, Si 0.13%, S 0.03%, P 0.03%, Ni 3.66%, Cr 1.45%.

Its physical properties were those given below as Sample 1. Sample 2 represented another chrome-nickel steel made for the same purpose, containing 3½% of nickel.

| | Sample 1 | Sample 2 |
|---|---|---|
| Tensile strength, pounds per square inch | 119,000 | 138,000 |
| Elastic limit, pounds per square inch | 106,000 | 119,000 |
| Elongation in 2 inches, per cent | 22 | 22 |
| Contraction of area, per cent | 61 | 49 |

Such steel is most excellent for use on war-ships to form protective decks and barriers to protect from secondary battery fire. Chrome-nickel-vanadium steel is also used for this purpose.

**Projectiles.**—Nickel-chromium steel is used in the manufacture of most armor-piercing projectiles.

Cubillo cites a steel for projectiles having 0.48% C, 0.58% Mn, 0.75% Cr, 2.55% Ni, 0.40% Si, 0.04% P. A test piece quenched in oil and tempered had an elastic limit of 129,400 pounds per square inch, a tensile strength of 150,300 pounds per square inch, and an elongation of 19%.

For large projectiles Girod prefers chromium-tungsten steel having 0.50% C, 4% Ni, 0 to 1.5% Cr, and 0.25% W.

It is curious that nickel is considered to improve the quality of shot although gen-

erally held to injure the quality of high-speed tool steels. In use there seems to be a parallel between the requirements of the two, except for the important and vital difference as to the required speed at which they respectively meet the metal to be penetrated. The speed of impact of the shot enables it to enter when no amount of pressure will effect the same result.

**Hollow Shaft.**—Following is a description of the manufacture of a large shaft of mild chrome-nickel steel for marine purposes. A corrugated 35-ton ingot 45 inches in diameter was made of basic open-hearth steel having 0.24% C, 0.70% Mn, 0.013% P, 0.015% S, 0.18% Si, 1.60% Ni, and 0.32% Cr. A few hundredths per cent of titanium was added in the ladle, but did not appear in the steel. The shaft when finished was $14\frac{1}{2}$ inches in diameter, with an 8-inch hole through the center line.

The steel was melted without the addition of ore late in the heat, a method that favored soundness and tended to allow the steel to clean itself of insoluble impurities such as oxides and silicates. The ingot was forged, annealed at 866° C. (1,590° F.), bored, rough-turned, heated to 750° C. (1,382° F.), quenched in oil, and drawn at 593° C. (1,100° F.).

The shaft was merely raised to the drawing temperature, 593° C., when firing at once ceased, the furnace was closed, and the shaft allowed to cool with the furnace.

The averages of the tests, which were longitudinal, were as follows: Tensile strength, 83,300 pounds per square inch; elastic limit, 52,500 pounds per square inch; elongation in 2 inches, 26%; contraction, 60%. The results were excellent, though seemingly a lower drawing temperature, which would have resulted in a higher elastic limit, would have been justified.

**Castings** are made also of chrome-nickel steel and may be used in the annealed or heat-treated condition.

Composition and Properties of Chrome-Nickel Steel Castings

| Sample No. | Composition | | | | | | | Tensile Properties | | | | Condition |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Mn | Si | S | P | Ni | Cr | Tensile Strength | Elastic Limit | Contraction of Area | Elongation in 2 Ins. | |
| | % | % | % | % | % | % | % | Lbs. | Lbs. | % | % | |
| 1..... | 0.30 | 0.41 | .... | 0.04 | 0.03 | 3.64 | 1.49 | 91,500 | 45,500 | 24 | 16.5 | Annealed |
| 2..... | .33 | .39 | .... | .04 | .03 | 3.58 | 1.61 | 90,500 | 46,500 | 27 | 18.5 | Annealed |
| 3..... | .30 | .20 | 0.35 | .... | .... | 2.50 | .50 | 110,000 | 80,000 | 30 | 20 | Heat-treated |

**Mayarí Steel.**—A so-called natural chrome-nickel steel is now made from certain ores mined at Mayarí, Cuba. The ores carry enough nickel to give 1.3 to 1.5% of nickel, and enough chromium to give $2\frac{1}{2}$ to 3% of chromium in the crude iron smelted therefrom. When the iron is converted into steel by the pneumatic or open-hearth processes, the nickel is practically all present in the steel, but the chromium is of necessity largely wasted by being oxidized.

Steel made in part of Mayarí iron is giving good service in rails, and particularly in track bolts, which are heat-treated to give the metal an elastic limit of 75,000 pounds per square inch.

Why these rails are satisfactory when other chrome-nickel steels were not has not been explained. The chief differences seem to be (1) that these Mayarí steel rails have less of the alloying elements because Mayarí iron is used only in part in them, and (2) that the steel is made in the open-hearth furnace.

The use of steel containing Mayarí iron is increasing, and the demand is enough to induce the production synthetically of steels of the same composition by adding nickel and chromium to simple steels in the Mayarí proportions.

## SILICON STEELS

Silicon steels are generally made in the open-hearth furnace, preferably on an acid hearth, as the acid slag does not waste the silicon in the final additions as rapidly as does a basic slag that contains free oxide of iron, and therefore the final content of silicon desired may be more closely controlled.

Silicon in true silicon steels must be added to the charge only a short time before teeming, as any oxygen that reaches the metal will largely be taken up by the silicon which will be wasted by burning to silicic acid ($SiO_2$). When so added to a bath in proper condition as to temperature and amount of dissolved oxygen or oxides the silicon will overwhelm the gases in solution, and the steel as cast will be free from blow-holes and with a maximum tendency to pipe.

Because of the large proportion of silicon in silicon steels and because of the short time allowable after the silicon has been added to the bath, it should be added in the heated or molten state.

**Properties.**—Silicon steel containing 0.20% of carbon may be rolled if the silicon content is less than 7%. With 0.90% carbon it may be rolled if the silicon is less than 5%. With a silicon content higher than 5% the metal is useless. In structural steels the effect of the silicon is to raise the elastic limit to a moderate degree. Silicon lowers the coefficient of expansion of steel somewhat as nickel does.

Composition and Properties of Structural Silicon ("Silico-Manganese") Steels

| Sample No. | Description | C | Si | Mn | S | P | Tensile Strength | Elastic Limit | Elongation | Contraction | Ball Hardness |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % | % | % | % | % | Lbs. | Lbs. | % | % | |
| 1..... | Automobile springs... | 0.50 | 2.00 | 0.70 | 0.04 | 0.03 | ..... | ..... | ... | ... | ... |
| 2..... | Springs treated...... | .47 | 1.83 | .70 | .01 | .01 | 254,000 | 230,000 | 9 | 40 | ... |
| 3..... | Carriage axles....... | .50 | 1.90 | .70 | .04 | .04 | ...... | ...... | ... | ... | ... |
| 4..... | Test piece, natural condition......... | .48 | 1.40 | .45 | ... | ... | 113,760 | 71,100 | 17 | ... | ... |
| 5..... | Test piece, treated... | .48 | 1.40 | .45 | ... | ... | 177,750 | 149,310 | 14 | ... | ... |
| 6..... | Test, treated........ | .50 | 1.75 | .65 | ... | ... | ...... | 198,700 | 8.5 | 21 | 418 |
| 7..... | Annealed........... | .36 | 1.27 | .57 | .03 | .02 | 94,500 | 59,750 | 25 | 48 | ... |
| 8..... | Drawn at 427° C..... | .36 | 1.27 | .57 | .03 | .02 | 182,200 | 160,850 | 12.5 | 34 | ... |
| 9..... | Drawn at 427° C..... | .31 | 2.39 | .48 | .03 | .05 | 134,750 | 104,700 | 22 | 55 | ... |

The treated test piece comprising sample 5 was heated to 954° C. (1,750° F.), quenched in water, and drawn at 427° C. (800° F.). The hardening temperature of samples 8 and 9 was probably about the same as that of sample 5.

**Uses.**—The chief structural use of silicon-alloy steel is in springs of the leaf type for automobiles and other vehicles. The silicon is considered to make the springs somewhat tougher so that they are less liable to break in service than springs of simple steel. In the trade this steel is called silico-manganese steel, though its content of manganese is usually no more than is common in simple steels.

In electricity, an important use for silicon-alloy steel is in the cores of static transformers. With the exception of manganese, most of the elements employed in making alloy steels, although not greatly decreasing the magnetic susceptibility of the iron that contains them, lower its hysteresis loss. Silicon is the element most used for that purpose because it is the cheapest, but aluminium, phosphorus, nickel (3½%), and tungsten have a similar effect.

The silicon content in silicon transformer metal is usually between 3½ and 4½%, or, more exactly, 4 to 4½%. The steel is rolled into thin sheets which, for one large

user, are 0.014 inch thick; the transformer cores are built up of these sheets, which are cut to shape separately by stamping. For low induction the permeability of this steel is nearly as great if not greater than that of any other variety of iron or iron alloy known, and its hysteresis loss is less than that of any other of nearly as low cost.

The results of an analysis of a transformer core made of silicon-alloy steel are as follows: C, 0.08%; Si, 4.18%; Mn, 0.11%; S, 0.06%; P, 0.01%; Al, 0.01%.

**Case-hardening.**—Silicon steels can not be case-hardened, as the silicon retards the absorption of carbon; the silicon content must therefore be low, not over 0.04%, in steel intended to be so treated.

## HIGH-SPEED TOOL STEELS

High-speed tool steels, also called rapid steels, have worked a revolution in the machine-shop business of the whole world, affording largely increased outputs and commensurate lower costs. The revolutionary feature wherein tools made of these steels differ from and exceed in service the tools formerly used is their ability to maintain a sharp strong cutting edge while heated to a temperature far above that which would at once destroy the cutting ability of a simple steel tool. Because of this property a tool made of high-speed tool steel can be made to cut continuously at speeds three to five times as great as that practicable with other tools, and when, as the result of the friction of the chip on the tool, it may be red-hot at the point on top where the chip rubs hardest, and the chip itself may, by its friction on the tool and the internal work done on it by upsetting it, be heated to a blue heat of 296° C. (565° F.) or even hotter, to perhaps 340° C. (644° F.).

**Manufacture.**—High-speed tool steels are all made by the crucible or electric-furnace process. The crucibles or pots are made of graphite. The average life of the crucibles or pots varies in different works from six to nine melts. In packing a pot with a charge for rapid steel the tungsten must be placed on top of the charge—as with simple tungsten steel—to guard as far as possible against the tendency of the tungsten to settle because of its high specific gravity. That tendency seems to be less with the rapid steels than with the simple tungsten steels.

High-speed tool steel as cast has a coarse structure and dark color as compared with the structure and color of simple steels of the same carbon content. A corner is broken from the top of each ingot, to show the grain, and the ingots when hand-poured directly from the pots are classified by the eye as in the production of simple crucible steels. If the ingots are cast from the large ladle a test is taken for analysis which determines the disposition of the whole ladleful of steel.

The ingots run from 3½ by 3½ inches to 16 by 16 inches, but most of them are from 5 by 5 inches to 9 by 9 inches. For hot-working they are heated in a furnace chamber having a temperature of about 1,180° C. (2,156° F.). At this high heat the steel may be worked satisfactorily under the hammer or press and may be quickly worked down to the dimension desired.

**Composition.**—The tendency of the makers is toward a somewhat uniform composition as regards the contents of the alloying elements, whose benefits have become fairly well known, and whose use as a consequence may be considered as established. Specifically, these alloying elements are tungsten and chromium. The addition of vanadium and cobalt in important proportions is considered by some makers to give distinct improvement to high-speed steel, and some vanadium is almost always present.

The analyses on following page are of steels recently made, most of which are considered to be good commercial steels.

Samples D—1 and E—1 gave excellent results in a competitive test, whereas samples D—2, D—3, E—2, and E—3, manufactured by the same makers, gave distinctly inferior results in the same shop.

The occurrence of nickel in four of the samples may have been accidental, having been due to nickel in some of the scrap steel used in the charge. Most makers now put in vanadium, and steel like that represented by sample G, which had the highest vanadium content of all the samples represented in the table, was the winner in a recent competitive test.

The average specific gravity of the steels represented in the table was about 8.8, the increase over the specific gravity of iron being due chiefly to the tungsten content.

There are so many factors besides the ultimate composition that affect the value of rapid tool steels that no conclusion can be drawn from the analysis alone.

**Carbon.**—The proportion of carbon aimed at in high-speed tool steels is about 0.65%, which in a simple steel would not be enough to give the maximum hardness even if the steel were heated above the critical point and quenched in water, and still

Results of Analyses of High-Speed Steels Made in 1913 or 1914

| Sample [a] | C | Mn | Si | S | P | Cr | W | V | Co | Ni | Mo | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | % | % | % | % | % | % | % | % | % | % | |
| A....... | 0.65 | 0.15 | 0.20 | 0.02 | 0.03 | 4.75 | 17.50 | 0.90 | .... | .... | .... | |
| B—1.... | .66 | .27 | .14 | .04 | .05 | 4.51 | 17.48 | .70 | 4.22 | 0.17 | .... | |
| B—2.... | .74 | .31 | .13 | .04 | .02 | 4.20 | 15.63 | .67 | 2.70 | .... | .... | |
| B—3.... | .63 | .14 | .07 | .04 | .05 | 4.26 | 17.16 | .45 | 3.80 | .20 | .... | |
| B—4.... | .69 | .34 | .14 | .03 | .04 | 5.28 | 16.35 | .64 | 5.28 | .... | .... | |
| C—1.... | .66 | .22 | .17 | .03 | .02 | 3.44 | 16.51 | .73 | .... | .... | .... | |
| C—2.... | .64 | .21 | .16 | .03 | .03 | 3.30 | 16.06 | .66 | 4.02 | .... | .... | |
| C—3.... | .67 | .33 | .25 | .02 | .02 | 3.85 | 16.06 | .70 | .... | .... | .... | |
| D—1... | .75 | .28 | .36 | .03 | .... | 4.10 | 19.00 | .75 | .... | .... | .... | Good |
| D—2... | .68 | .38 | .40 | .03 | .... | 4.65 | 17.85 | .53 | .... | .... | .... | Inferior |
| D—3... | .69 | .36 | .38 | .04 | .... | 4.67 | 17.90 | .50 | .... | .... | .... | Inferior |
| D—4... | .57 | .20 | .26 | .02 | .03 | 4.82 | 15.38 | .50 | .... | .... | .... | Inferior |
| E—1.... | .61 | .23 | .35 | .04 | .... | 4.10 | 17.20 | 1.00 | .... | .... | .... | Good |
| E—2.... | .68 | .45 | .40 | .04 | .... | 4.00 | 14.26 | 1.09 | .... | .... | .... | Inferior |
| E—3.... | .70 | .50 | .39 | .05 | .... | 4.08 | 14.50 | 1.07 | .... | .... | .... | Inferior |
| E—4.... | .60 | .23 | .12 | .03 | .02 | 3.90 | 17.27 | .90 | .... | .... | .... | Inferior |
| F....... | .64 | 2.29 | .12 | .02 | .01 | 4.39 | 16.09 | .59 | .... | .28 | .... | |
| G....... | .72 | .37 | .18 | .03 | .02 | 4.50 | 13.30 | 2.50 | .... | .... | .... | |
| H—1.... | .77 | .16 | .21 | .02 | .02 | 4.05 | 18.64 | 1.35 | .... | .... | .... | |
| H—2.... | .67 | .16 | .20 | .02 | .02 | 4.66 | 13.86 | 1.08 | .... | .... | .... | |
| I....... | .64 | .23 | .29 | .02 | .02 | 4.57 | 19.10 | .54 | .... | .... | .... | |
| J—1.... | .64 | .30 | .26 | .02 | .01 | 2.93 | 18.71 | 1.22 | .... | .... | .... | |
| J—2.... | .71 | .14 | .26 | .03 | .03 | 2.97 | 18.21 | .97 | .... | .... | .... | |
| K—1.... | .55 | Tr. | .23 | .02 | .04 | 4.46 | 16.05 | .80 | 4.72 | .... | 0.72 | |
| K—2.... | .70 | Tr. | .18 | .01 | .02 | 4.25 | 15.50 | .88 | 4.72 | .18 | .67 | |
| K—3.... | .74 | .31 | .13 | .04 | .02 | 4.20 | 15.63 | .67 | 2.70 | .... | .... | |

[a] Samples A to I represented American steels, the numerals indicating different samples from the same maker; sample J represented an English steel; sample K represented a German steel.

less so when the steel is cooled as slowly as these steels are in their treatment. This shows that the carbon acts in a different way from what it does in simple steels.

**Tungsten** is well established as a most important if not indispensable ingredient of commercial tool steels, being almost or quite universally used in quantity therein. The best proportion of tungsten, all things considered, seems to lie between 16 and 20%, the tungsten content in 95% of all the American steels coming within these limits. Some published analyses of European high-speed tool steels show a higher content of tungsten than this, but American makers generally agree that any tungsten in excess of 20% adds nothing to the usefulness of the steel, and they therefore make that proportion the upper limit of the amount added. One effect of the tungsten is that the best percentage of carbon in rapid steel is but about half that required in simple tool steels intended for the same kind of service.

**Chromium.**—The effect of chromium in high-speed tool steel, as in other steels, is undoubtedly, as a hardener, entering into the double carbide of tungsten and chromium which gives or causes the proper cutting edge. Although the proportion of this element present

in these steels varies considerably, it is always large, perhaps never less than 2% or more than 6% in American steels, and in European steels the upper limit is at least 9%.

**Molybdenum.**—The use of molybdenum in high-speed tool steels is being generally discontinued. Some makers for years manufactured molybdenum tool steels, but as a rule they have either wholly discontinued its use or use a much smaller proportion than formerly, employing it as an auxiliary rather than a major constituent.

The effect of molybdenum is similar to that of tungsten, but is more intense in that 1% molybdenum is currently considered to give about the same or greater hardening effect than 2% of tungsten. It gives a fine cutting edge.

Various reasons are assigned for the discontinuance of the use of molybdenum in these steels. Taylor found that molybdenum in rapid steels caused irregular performance; that steels of nearly the same composition and having had seemingly the same treatment gave large variations in the cutting speeds they would stand. One user specifies no molybdenum because it causes the tools to crack in quenching. A maker objected to molybdenum because molybdenum steel was apt to be seamy and to contain physical imperfections.

**Vanadium** is used for high-speed tool steel in varying amounts, most makers using at least 0.5%, although some run the vanadium content up to $1\frac{1}{2}$ or $1\frac{3}{4}$%, or even more, considering that such an addition increases in an important degree the value of the steel for tools.

The effect of vanadium is considered to resemble in some ways that of chromium in increasing the hardness or red-hardness of the cutting edge.

High-speed steels containing vanadium are generally classed as "superior" steels, and many, though not all, makers and users consider them distinctly better than the "standard" steels containing no vanadium, both on account of their actual cutting qualities at high speeds and on account of the length of time a tool will cut before it needs regrinding. The true value of vanadium in rapid steels must probably be held as not yet fully determined.

**Cobalt** now threatens to change tool-steel manufacture because of the properties it imparts. The recent great decline in price following the increase of the supply from the silver ores of the cobalt district in Ontario naturally led to its trial as a steel-alloying element, and some most excellent high-speed steels containing, in addition to the usual ingredients, about 4% of cobalt, have been obtained. This result was hardly to have been expected in view of the experience with nickel, which cobalt much resembles, as nickel has been condemned by nearly every manufacturer as not being a desirable ingredient of high-speed tool steels, because of the effect it has of making the edge soft or "leady." The cobalt steel, however, has shown, in some products at least, increased ability to hold its edge in work.

One user of cobalt steel found it better suited for turning manganese steel than any other steel he tried, his success being so marked as to make it practically a commercial operation. Manganese steel, as noted elsewhere, is so hard as to be considered practically unmachinable, the usual practice having been to finish it by grinding when necessary.

The valuable effect of cobalt is claimed to be that it increases the red-hardness of high-speed tool steel, enabling the steel to cut at a higher speed.

**Copper** has been considered to be highly injurious in high-speed tool steel, even as little as 0.05% being inadmissible; and it is thought to be particularly harmful if much sulphur is present in the steel; also the higher the carbon content the more harmful is the copper.

**Sulphur and phosphorus,** which are so deleterious in simple tool steels, are considered to be somewhat less so in high-speed steels, in which the effect is either modified or else masked by the large quantities of other ingredients. Some commercial brands of high-speed steels have as much as 0.05% of each of these impurities, to which no inferior quality is attributable.

## STELLITE

Stellite, though a competitor of high-speed steels, is not within the scope of our subject, but a recent analysis is given of a sample for such interest as it may have in relation to cutting steels.

ANALYSIS OF STELLITE

| Constituent | Per cent |
|---|---|
| Cobalt | 59.50 |
| Chromium | 10.77 |
| Molybdenum | 22.50 |
| Carbon | .87 |
| Silicon | .77 |
| Manganese | 2.04 |
| Sulphur | .084 |
| Phosphorus | .040 |
| Iron | 3.11 |
| Tungsten | 0 |
| Nickel | 0 |
| | 99.684 |

## CHROMIUM-VANADIUM STEELS

Chromium-vanadium steels, usually called in the trade chrome-vanadium steels, are the latest development in structural alloy steels that have gained an extensive market. These steels are almost all made in the open-hearth furnace, the chromium and vanadium alloys being added shortly before casting.

The hot working of chrome-vanadium steels presents no especial difficulties. The total amount of alloying elements is not large in the commercial grades, and the steel acts in the press and rolls much like simple steels with somewhat higher carbon contents.

Chrome-vanadium steels are in their physical properties much like chrome-nickel steels, but they have a greater contraction of area for a given elastic limit than the latter.

This higher contraction of area in the pulling test seems in some way to be associated with machinability, as chrome-vanadium steel with an elastic limit of 150,000 pounds per square inch may be machined rapidly, whereas a chrome-nickel steel having such an elastic limit would quickly dull the cutting tool if cut at the same speed.

COMPOSITION AND PROPERTIES OF CHROME-VANADIUM STEELS IN NATURAL STATE

| Sample No. | Composition | | | | | | | Tensile Properties | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Mn | Si | S | P | V | Cr | Tensile Strength | Elastic Limit | Contraction of Area | Elongation in 2 Ins. | Ball Hardness |
| | % | % | % | % | % | % | % | Lbs. | Lbs. | % | % | |
| 1 | 0.57 | 0.84 | 0.27 | 0.03 | 0.01 | 0.31 | 1.36 | 98,000 | 75,750 | 68.5 | 28.1 | 175 |
| 2 | .46 | .48 | .20 | .02 | .01 | .14 | 1.17 | 82,250 | 52,500 | 71.0 | 34.0 | 160 |
| 3 | .18 | .32 | .18 | .02 | .01 | .20 | .74 | 60,500 | 42,900 | 75.0 | 43.0 | 133 |
| 4 | .30 | .65 | .10 | .04 | .04 | .18 | .90 | ..... | 45,000 | 69.0 | 35.0 | [a]155 |

[a] Annealed.

The greater part of the chrome-vanadium steels made goes into automobiles. They are preferred by some because of their greater freedom from surface imperfections, notably seams, which steels containing nickel are prone to have if the ingots are at all unsound. Vanadium is a deoxidizer, whereas nickel is not, so that vanadium, when present, favors quality, and the smaller proportion required enables it to compete with nickel even though its cost is five or six times as great.

Chrome-vanadium steels are nearly always used in the heat-treated condition, but there are exceptions even in automobiles, as some frames, forgings, and shafts are made of the steel in its natural state. When heat treated these steels are both hardened and drawn at slightly higher temperatures than are used with nickel-chromium steels

to get similar properties. These temperatures are given in the table of heat-treated chrome-vanadium steels.

Some chrome-vanadium steel is said to be used in armor plate of medium thickness (4 inches), which is not face-hardened but has high properties imparted by heat treatment. Some such steel is used in high-duty forgings and structural parts of machines.

Composition and Properties of Chrome-Vanadium Steels in Heat-Treated State

| Sample No. | Composition | | | | | | | Tensile Properties | | | | | Treatment [a] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Mn | Si | S | P | Cr | V | Tensile Strength | Elastic Limit | Contraction of Area | Elongation in 2 Ins. | Ball Hardness | |
| | % | % | % | % | % | % | % | Lbs. | Lbs. | % | % | | |
| 1 | 0.30 | 0.65 | 0.10 | 0.04 | 0.04 | 0.90 | 0.18 | ..... | 101,000 | 64 | 20 | 255 | 899° W; 704° A. |
| 2 | .30 | .65 | .10 | .04 | .04 | .90 | .18 | ..... | 180,400 | 43 | 10 | 430 | 899° W; 454° A. |
| 3 | .30 | .65 | .10 | .04 | .04 | .90 | .18 | ..... | 200,000 | 52 | 10 | 429 | 899° W; 315° A. |
| 4 | .28 | .45 | .26 | .02 | .01 | 1.00 | .18 | 96,500 | 79,000 | 75 | 34 | 187 | 899° O; 676° A. |
| 5 | .40 | .75 | .26 | .01 | .01 | 1.00 | .17 | 148,000 | 120,000 | 53 | 20 | 270 | 926° O; 676° A. |
| 6 | .40 | .75 | .26 | .01 | .01 | 1.00 | .17 | 221,000 | 200,000 | 48 | 11 | 435 | 926° O; 426° A. |
| 7 | .57 | .37 | .20 | .02 | .01 | .69 | .22 | 188,200 | 177,500 | 57 | 14 | 330 | ——; 426° A. |
| 8 | 1.06 | .36 | .22 | .02 | .02 | .95 | .11 | 135,550 | 126,750 | 49 | 21 | 248 | ——; 648° A. |
| 9 | .41 | .49 | .12 | .03 | .03 | 1.09 | .11 | 86,900 | 77,250 | 70 | 33 | 152 | ——; 754° A. |
| 10 | .25 | .50 | .10 | .03 | .02 | .95 | .75 | 131,700 | 113,100 | 56 | 18 | .... | .............. |

[a] The first temperature given for each sample is that at which the steel was quenched, and the second the drawing temperature; W, O, and A represent water, oil, and air, the three cooling media used. Samples 8, 9, and 10 were hardened before being drawn at the temperatures given.

## EXAMPLE OF SATISFACTORY USE OF CHROME-VANADIUM STEEL

A hydroelectric plant had shafts 6½ inches in diameter, which transmitted 3,000 kilowatts each at 480 revolutions per minute, and all broke in service. The shafts were made of untreated nickel steel having an elastic limit of about 40,000 pounds per square inch. To make stronger shafts by increasing their size not being practicable, other shafts were made under the specification that the elastic limit of the steel should be at least 105,000 pounds per square inch, its contraction of area 40%, and its ball hardness uniform within 5%. Shafts to meet such qualifications were made of chromium-vanadium steel containing 0.33% C, 0.54% Mn, 0.022% P, 0.030% S, 0.89% Cr, and 0.24% V. The ingot, which was 30 by 25 inches in section, was rolled to an 18 by 18 inch bloom or billet, and the shafts were forged therefrom. The shafts were heat-treated, and a test from one of them, about the average of all those made, pulled at Watertown Arsenal on a 2-inch by 0.505 diameter section, gave results as follows:

Results of Tests of Heat-Treated Chrome-Vanadium Steel Shaft

| Elastic Limit | Tensile Strength | Elongation | Contraction | Ball Hardness |
|---|---|---|---|---|
| Pounds | Pounds | Per Cent | Per Cent | |
| 105,260 | 127,310 | 15 | 46.2 | 278 |
| ...... | ...... | .. | .... | 283 |
| ...... | ...... | .. | .... | 278 |

These shafts met the specifications and proved satisfactory in service.

## HEAT TREATMENT OF ALLOY STEELS

With few exceptions all alloy steels are heat treated for use, the treatment developing in them the high physical properties they are capable of possessing. No general law regarding the effects of heat treatment of alloy steels can be laid down. Some steels when quenched from a high heat are hardened and others are softened, the latter being generally those with the higher contents of certain of the alloying elements. In respect to the effects of heat treatment each steel is considered by itself.

For making small parts that must be true and well finished the structural alloy steels are generally heat-treated before they are machined, and this requirement prevents the use in such parts of steel of the highest strength attainable because steel having that strength is not commercially machinable. Generally speaking, any part that is to have an elastic limit of more than 100,000 pounds per square inch must be treated after having been machined, not before, because most steels having a higher elastic limit than that are too hard to allow machining by commercial processes, though chromium-vanadium steels with an elastic limit of 150,000 pounds per square inch are claimed to be machinable, that is, they may be cut with high-speed steels at a profitable rate. An elastic limit of 100,000 pounds or more per square inch can be imparted to steel only by heat treatment, as no untreated steel of a commercial grade will have so high a limit.

**The modulus of elasticity** of many, if not all, structural alloy steels in common with other steels is not changed much by heat treatment or variations in composition, and is usually between 28,000,000 and 30,000,000 pounds per square inch; that is, the modulus of the steel in its annealed, hardened, and tempered condition remains practically unchanged. The following table was compiled from data given by Landau:[a]

MODULI OF ELASTICITY OF SOME ALLOY STEELS

| Composition of Steel | | | | | | | | Modulus |
|---|---|---|---|---|---|---|---|---|
| C | Si | Mn | P | S | Cr | Ni | V | |
| % | % | % | % | % | % | % | % | |
| 0.50 | 0.13 | 0.82 | 0.01 | 0.02 | 1.25 | .... | 0.14 | 29,240,000 |
| .47 | 1.83 | .70 | .01 | .01 | .... | .... | .... | 28,950,000 |
| .48 | .16 | .44 | .01 | .01 | .98 | 2.02 | .... | 28,840,000 |
| .30 | .19 | .64 | .01 | .01 | .... | 3.25 | .18 | 28,260,000 |
| .25 | .21 | .74 | .01 | .01 | .... | 3.55 | .... | 28,170,000 |
| .24 | .21 | .46 | .01 | .02 | .96 | 2.02 | .... | 28,200,000 |
| .25 | .16 | .50 | .01 | .... | 1.05 | .... | .16 | 30,158,000 |

Because of the unchangeability of the modulus of elasticity the stiffness or rigidity of steel within the elastic limit is not changed either by heat treatment or the presence of any of the alloying elements, except perhaps manganese in manganese steel and nickel in high-nickel steels.

Heat treatment does increase the elasticity, however, so that a piece of heat-treated steel may return to its original form after having endured a stress that would have permanently deformed it in its untreated condition; that is, it is given some of the springiness of heat-treated springs.

## HEAT TREATMENT OF HIGH-SPEED TOOLS

The heat treatment given to high-speed steels for the commoner uses, as lathe and planer tools, has generally been simplified to heating to incipient fusion and quenching

[a] Landau, David, Influences affecting the fundamental deflection of leaf springs: Bull. Soc. Automobile Eng., vol. 5, March, 1914, p. 430.

in oil. Cooling by an air blast and double treatment, which were formerly recommended, are now not common, except that a second (drawing) heating is given to milling cutters and similar tools, the temperature imparted to the tool depending on the material to be cut.

The treatment is usually done by the blacksmith who heats the tool in his forge fire and then immerses it in a tank containing enough oil so that its temperature does not rise materially. Ten gallons of oil is a common quantity to use when the size and number of the tools are moderate, as in most shops. The fire is a deep compact coal fire, the coal in the center where the tool is heated being pretty thoroughly coked, that is, most of its volatile matter distilled out. This manner of heating has the advantage that free oxygen does not get at the tool to oxidize it, but its environment is non-oxidizing or even reducing, owing to the presence of an excess of burning carbon surrounding the tool. Any flame is more or less oxidizing, at least unless heavily charged with smoke or free carbon, and a piece of steel heated directly by a flame as in the ordinary heating chamber of a furnace is likely to be somewhat oxidized on its surface, the depth to which the oxygen penetrates varying according to the conditions, particularly the temperature, the access of air, and the length of time. Heating in a muffle will also result in oxidizing the steel unless extraordinary precautions are taken to keep out oxygen or to consume all that enters. The temperature of quenching, usually about 1,260° C. (2,300° F.), is determined by the fusion of the scale and its visible collection into drops or beads on the surface of the tool.

Quenching is done by quickly plunging the heated tool into the oil as soon as it has reached the desired temperature and moving it about in the oil until cold. Cooling in oil is thought by some to give a better tool than cooling in the air blast, one reason seemingly being the protection of the steel from free oxygen while it is hot enough to be oxidized thereby. The oxygen of the air blast forms a scale of oxide on the hot steel and the oxygen probably penetrates the metal below the scale to some extent, injuring the quality as deep as it goes. A tool on its second grinding, when the oxidized metal is removed, may then give better service than on the first, unless the first grinding has for that reason been heavy enough to remove the oxidized metal.

In some shops, however, the original treatment recommended by Taylor and White is given, the cutting edge of the tool being heated to incipient fusion and then immersed in a bath of melted lead at about 565° C. (1,050° F.). The heating is done in a small furnace over a deep coke fire, blown by an air blast, so that the environment of the tool while being heated is substantially non-oxidizing. Flames of carbonic oxide play out of the openings through which the tools are inserted, indicating little, if any, free oxygen within. In these shops, however, milling cutters and other tools that are machined to a particular form are treated by heating them to a slightly lower temperature, in order not to damage the cutting edges, and then plunging them into cold oil.

When cooled to the temperature of the lead it is taken out and placed in an air blast to complete the cooling. Some tools desired to be especially tough so as not to break in service are given a second heating to 565° C. and then cooled in the open air or air blast if saving time is important.

Rapid steel when well annealed will bend considerably without breaking, even in as large a section as 2½ by 1¼ inches, the bending being edgewise, as in a tool at work.

Whether a rapid steel is made harder by the heat treatment given it depends somewhat on the condition of the bar before treatment. If it has previously been annealed, the treatment hardens it, whereas heat treatment may not harden a piece in the natural state. Taylor found that some tools having useful red-hardness could be filed rather readily. Edwards, on the other hand, found treated high-speed steels to be exceedingly hard—as hard as any steel could be made by quenching. Gledhill found that high-speed steel was good for turning chilled rolls, which are extremely hard and require the hardest kind of tool to cut them.

The hardness of the steel when cold is not the determining factor of usefulness in any case. It is the hardness when heated under conditions of work.

The cutting edge of a rapid-steel tool at work is probably never as hot as the metal

just back of it, where the heating caused by the friction of the chip, as it is deflected and rubs hard on the tool, is most intense. The edge itself is kept relatively cool by the cold metal flowing upon it.

## THEORY OF HIGH-SPEED STEELS

The researches of Carpenter and Edwards on the heating and cooling of high-speed steels have shown that such steels have an extraordinary stability of composition after they have been heated to 1,200° C. (2,192° F.) or more, and that a second heating of 550° C. (1,022° F.) has no softening or drawing effect. It seems fairly evident that red-hardness depends on or is the natural result of these facts.

At a temperature higher than 1,200° C. (2,192° F.) a double carbide of chromium and tungsten is formed, which persists largely even when the steel is cooled slowly as in the open air, and more so when cooling is accelerated. This double carbide imparts to the steel a high degree of hardness and is stable at all temperatures up to 550° C. (1,022° F.) or somewhat higher. At 550° C. the steel has a low red color visible in the dark.

If the above theory be true, then at a temperature of 1,200° C. (2,192° F.) the chromium and tungsten must have a stronger affinity for carbon than iron has, whereas at lower temperatures, say from around 930° C. down to the critical point, the affinity of carbon for iron is slightly stronger than that of either chromium or tungsten or both, and the carbon then exists wholly or in part as carbide of iron, or a complex carbide of iron with one or both of the other elements.

Carbide of iron, or hardening carbon which causes the hard condition of iron in simple steel that has been quenched from a temperature higher than the critical point, is unstable at even slight elevations of temperature above atmospheric temperature, its unstableness increasing with the degree of heat, though not being proportional thereto. Boynton has shown that between 400° C. (752° F.) and 500° C. (952° F.) the amount of change and consequent softening is much greater than at other temperatures, either lower or higher.

The proportion of carbon in rapid steel should perhaps be only as much as will combine with the chromium and tungsten at 1,200° C. (2,192° F.) and leave none to exist as unstable hardening carbon of hardened simple steel.

**Testing.**—A reliable and inexpensive method of quickly testing high-speed steels to show their value is much needed, as Taylor has explained. Herbert and Edwards have used and recommended machines and methods that lessen the time and trouble of testing, but no test seems to take the place of a trial at actual work because the performance of a tool in one line of work with certain conditions may not be foretold positively by its performance in another with different conditions. Among the reasons are that (1) sometimes greater durability is obtained by changing, that is, increasing or lessening, the speed of the cut, thus changing also the temperature of the tool, or (2) a given tool when used at its best speed may be excellent for cutting a certain material, yet prove inferior to another tool for cutting a different material. Thus if selected as the best by trial for cutting a 0.20% carbon steel it may be surpassed by others in cutting a 0.70% carbon steel.

Physical tests of rapid steels at different temperatures up to 800° C. (1,472° F.) are needed to show the effect of heat on the physical properties of those steels. New uses would probably be suggested by the results of such a series of tests.

A rapid-steel tool does not finish the piece being cut as nicely as does a simple steel tool, as the rapid steel does not keep a fine edge with a light cut and slow speed of, say, 20 feet per minute. The durability of such a tool taking a light cut is much greater at a higher cutting speed, at which the tool is hotter, showing that the strength or the toughness of the steel or both are augmented by the higher temperature. Unhardened simple steels with 0.6 to 0.7% carbon get stronger but less ductile with a rise of temperature up to about 300° C. (572° F.). If, as the temperature rises, high-speed steels get stronger without loss of ductility but perhaps with an increase, within limits of course, a physical reason for their great durability is provided.

In 1910, Herbert announced the discovery that any rapid-steel tool and some simple

steel tools may have two rather widely separated cutting speeds at which the tool is more durable than at speeds above, below, or between. Thus out of many cases described, one tool cooled in an air jet had nearly equal maximum durability at two speeds—50 and 90 feet per minute, whereas at 65 feet the durability was less than one-half of that at either of the other speeds. This discovery no doubt accounts for some of the anomalies encountered in tool steels as well as other steels, the properties or performances of which are not what would be expected from their composition and other attributes. Thus a tool may be condemned when an increase of its cutting speed would cause it to give satisfactory service and durability.

Rapid steel will do its best cutting when hot. A desirable practice followed in some shops, is to heat a tool to near redness before putting it to work.

# MILL AND FOUNDRY PRODUCTS

Covering Structural Steel, Reinforcement Steel for Concrete, Boiler Plating, Hull Plating, Wrought Iron, Steel Castings, Steel Forgings, Cast-Iron and Malleable Castings.

## NAVY DEPARTMENT

1. **Mill Orders.**—The contractor shall furnish the Bureau of Yards and Docks, Navy Department, with complete copies of mill orders in triplicate. When so specified, the contractor shall arrange with the mill that no material shall be made or rolled until the inspection is arranged.

2. Steel shall be made by the open-hearth process.

3. Chemical qualities and physical properties shall conform to the following table:

| | Elements Considered | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Phosphorus, Maximum | | Sulphur, Maximum (per Cent) | Maximum Tensile Strength (Pounds per Square Inch) | Elongation | | Character of Fracture | Cold Bends Without Fracture |
| | Basic (per Cent) | Acid (per Cent) | | | Minimum per Cent in 8 Ins. | Minimum per Cent in 2 Ins. | | |
| Plates, shapes, and bars | 0.04 | 0.06 | 0.05 | 55,000 65,000 | 25 | .. | Silky | 180° flat without fracture on outside of bend. |
| Rivet steel | .04 | .04 | .04 | 46,000–54,000 | 30 | .. | Do. | |
| Steel castings | .05 | .08 | .05 | [1]65,000 | .. | 15 | Silky or fine granular. | 90° d = 3t. |
| Wrought iron | ... | ... | ... | [1]48,000 | 15 | .. | 90 per cent fibrous | 135° d = 2t. |
| Steel forgings | .04 | .06 | .05 | 60,000–70,000 | 20 | .. | Silky | 180° around a bar of the same diameter. |
| Reinforcement steel for concrete: | | | | | | | | |
| Medium | .04 | .06 | .05 | 55,000–65,000 | 25 | .. | Do. | Do. |
| High carbon | .04 | .06 | .05 | 80,000–90,000 | 10 | .. | Do. | 135° around a bar of the same diameter. |
| Cast iron | ... | ... | ... | [1]18,000 | .. | .. | Gray granular. | |
| Hull plating | .04 | .06 | .04 | 55,000–65,000 | 25 | .. | Silky | 180° flat on itself without fracture on outside of bent portion. |
| Boiler plating | .04 | .06 | .04 | 55,000–65,000 | 25 | .. | Do. | Do. |

[1] Minimum.

Rivet steel, when nicked slightly on one side and bent around a bar of the same diameter as the rivet rod, shall give a uniform fracture. Wrought iron, when nicked all around and bent, shall show a fracture at least 90 per cent of which is fibrous.

4. **Allowable Variation in Physical Properties.**—If first test shows maximum strength for plates, shapes, bars, or rivet steel to be outside of prescribed limits, two additional tests shall be made from material of the same gauge, and if both comply with the specified requirements the material will be accepted.

5. **Allowable Variation in Weight.**—A variation of more than 2½ per cent from the specified cross-section or weight of any piece of rolled steel shall be sufficient cause for rejection, except in case of sheared plates, which shall be governed by the following permissible variations applying to single plates: Plates will be accepted if they measure not more than 0.01 inch below the ordered thickness; an excess over the nominal weight, corresponding to the dimensions as shown in the following table:

| Thickness Ordered | Nominal Weights | Width of Plate | | | |
|---|---|---|---|---|---|
| | | Up to 75 Inches | 75 Inches and Up to 100 Inches | 100 Inches and Up to 115 Inches | Over 115 Inches |
| | *Pounds* | *Per Ct.* | *Per Ct.* | *Per Ct.* | *Per Ct.* |
| ¼-inch | 10.20 | 10 | 14 | 18 | .. |
| 5/16-inch | 12.75 | 8 | 12 | 16 | .. |
| ⅜-inch | 15.30 | 7 | 10 | 13 | 17 |
| 7/16-inch | 17.85 | 6 | 8 | 10 | 13 |
| ½-inch | 20.40 | 5 | 7 | 9 | 12 |
| 9/16-inch | 22.95 | 4½ | 6½ | 8½ | 11 |
| ⅝-inch | 25.50 | 4 | 6 | 8 | 10 |
| Over ⅝-inch | ..... | 3½ | 5 | 6½ | 9 |

6. **Finish.**—Finished material shall be free from injurious seams, flaws, cracks, defective edges, or other defects and have a smooth, uniform, and workmanlike finish. Plates 36 inches in width and under shall have rolled edges unless otherwise specified by the bureau.

7. **Steel Castings.**—All steel castings shall be true to drawing and shall be annealed to remove all internal stresses. Castings shall be free from cold shuts, sand holes, blow-holes, and any other defects which would tend to make them unsuitable for the service contemplated.

8. **Wrought Iron.**—Wrought iron shall be double-rolled, tough, fibrous, uniform in character, entirely free from steel scrap, thoroughly welded in rolling, and free from surface defects.

9. **Malleable Castings.**—Castings shall be true to drawing, free from blemishes, scale, or shrinkage cracks. They shall be well decarbonized without being burned or overheated. Test specimens shall bend 90° around three times their least diameter without fracture. In case of important castings, tension tests shall be furnished when required.

10. **Steel Forgings.**—Fo gings shall be free from cracks, flaws, seams, or other injurious imperfections, and shall conform to dimensions shown on drawings and be made and finished in a workmanlike manner.

11. **Cast Iron.**—Cast iron shall be of tough, gray iron, free from cold shuts and blow-holes. A hammer blow on a sharp edge of the casting shall produce an indentation without flaking the metal.

12. **Stamping.**—Every finished piece of steel shall have the melt number and the name of the manufacturer stamped or rolled upon it. Steel and pins for rollers shall be stamped on the end. Rivet and lattice steel and other small parts may be bundled with the above marks on an attached metal tag.

13. **Rules Governing Physical Tests.**—(a) Specimens for tensile and bending tests for plates, shapes, and bars shall be cut from the finished product, and shall have both faces rolled and both edges milled to the form shown by Fig. 1, or have both edges parallel throughout; or they may be turned to a diameter of ¾ inch for a length of at least 9 inches, with enlarged ends.

(b) Test specimens of rivet steel shall be of the full size of the rod.

(c) For pins and rollers test specimens shall be cut from the finished bar, in such a manner that the center of the specimen will be one-fourth of the diameter from the surface of the bar. The specimens for tensile tests shall be turned to the form shown by Fig. 2. The specimens for bending tests shall be 1 inch by ½ inch in section. Specimens taken from pins and rollers over 1½ inches in diameter shall be taken in such a manner that the center of the specimen shall be one-fourth of the diameter of the bar from the surface. For bars under 1½ inches in diameter, the specimen shall be taken from as near the surface as possible.

(d) Specimens representing steel castings shall be made from coupons which are molded, cast, and annealed as integral parts of the castings and which are not cut from the castings until after the completion of the annealing process.

Individual coupon tests and reports will be made for each heat unless otherwise elsewhere specified.

14. **Tests and Test Reports.**—Chemical determinations of the percentages of carbon, phosphorus, sulphur, and manganese shall be made by the manufacturer and certified copies in triplicate of such analysis shall be furnished the inspector (or the Bureau of Yards and Docks in case no inspector has been detailed).

The manufacturer shall also make at least one set of physical tests from each melt of steel and each lot of iron as rolled or cast. In case steel differing ⅜ inch and more in thickness is rolled from one melt, a test shall be made from the thickest and thinnest material rolled. Each set of tests will include the determination of maximum tensile strength, elongation, character of fracture, cold bending, and yield point as indicated by drop of beam.

In case the Government may desire check analyses at any time, such analyses shall be made at the expense of the Government, and an excess of 25 per cent will be allowed for such results, as compared with the limits prescribed in the table.

15. **Mill Tests and Inspections.**—Mill analyses, tests, inspections, and reports shall be made entirely by the manufacturer, or by the manufacturer subject to the supervision and direction of a Government inspector, as may be elected by the Bureau of Yards and Docks.

The contractor shall ascertain from the Bureau of Yards and Docks if the presence of a Government inspector is desired and arrange with the mill accordingly.

The manufacturer, at his own expense, shall furnish all facilities for inspecting and testing the weight and quality of all material at place of manufacture, and shall furnish suitable laboratory and testing machines and prepare samples and specimens for testing.

The inspector shall have free access at all times to all parts of the mill where material to be inspected by him is being manufactured or tested.

Analyses, tests, and inspections shall be made in accordance with recognized standard methods.

The manufacturer shall prepare and furnish the inspector, in triplicate (or the Bureau of Yards and Docks in case no inspector has been detailed), with complete certified copies of reports of tests. The manufacturer shall guarantee and be held responsible for the accuracy of all analyses, tests, inspections, and reports.

16. **Defective Material.**—Material which, subsequent to the prescribed tests at the mills and its acceptance there, develops weak spots, brittleness, cracks, or other imperfections, or is found to have injurious defects, will be rejected and shall be replaced by the manufacturer at his own expense.

17. **Shipping Invoices.**—Complete copies, in triplicate, of shipping invoices for each shipment shall be furnished the inspector, or be forwarded to the Bureau of Yards and Docks in case there has been no inspector detailed.

## SHOPWORK

18. **Shop Orders.**—The contractor shall furnish the Bureau of Yards and Docks with complete copies of the shop orders, in triplicate, and shall also notify the bureau at least 10 days before shopwork is to be commenced, in order that proper arrangements may be made for shop inspection.

19. **General Requirements.**—All members forming a structure shall be built in

accordance with approved drawings. Workmanship and finish shall be equal to the best practice in modern bridge work.

No material less than $\frac{5}{16}$ inch in thickness shall be used, except for fillers, beams, and channels, unless specifically required by contract.

Lattice bars shall have neatly rounded ends, unless otherwise specified.

Stiffeners shall fit neatly between flanges of girders, and where tight fits are called for the end of stiffener shall be faced and be brought to a true contact bearing with flange angles.

Web splice, plates, and fillers under stiffeners shall be cut to fit within $\frac{1}{8}$ inch of flange angles.

The clearance between ends of spliced web plates shall not exceed $\frac{1}{4}$ inch.

Finished members shall be free from twists, bends, or open joints.

Compression joints, depending upon contact bearing, shall have surfaces truly faced, so as to have full contact bearing when perfectly aligned and riveted up complete. All faces and surfaces shall be truly planed when so required by the contract.

The abutting ends and the bases of all columns shall be milled.

Pinholes shall be bored after members are riveted; they shall be true to gauge, smooth, straight, at right angles to the axis of the member, parallel to each other, and unless otherwise specified shall be accurately spaced to within $\frac{1}{32}$ inch.

Pins and rollers shall be accurately turned to gauge, and shall be straight, smooth, and entirely free from flaws. Diameter of pinholes shall not exceed diameter of pins by more than $\frac{1}{32}$ inch. Screw threads shall make tight fits in the nuts and shall be United States standard, except above the diameter of $1\frac{3}{8}$ inches, when they shall be made with six threads per inch.

Steel, except in minor details, which has been partially heated, shall be annealed.

Welds in steel will not be allowed.

Expansion bedplates shall be planed, true and smooth. Cast wall plates shall be planed on top. Cut of planing tool shall correspond with the direction of the expansion.

Pins, nuts, bolts, rivets, and other small details shall be boxed or crated. The weight of every piece and vox shall be marked on it in plain figures. In the case of boxed material both gross and net weight shall be marked.

20. **Preparation of Material Before Assembling.**—Material shall be thoroughly straightened in the shop by methods which will not injure it, and be cleaned of rust and dirt, if such exist, before being laid off or worked in any way.

Shearing shall be neatly done, and all portions of the work which will be exposed to view after completion shall be neatly finished.

Sheared edges of material over $\frac{3}{4}$ inch in thickness shall be planed to a depth of $\frac{3}{16}$ inch.

Surfaces in contact after assembling shall be painted before being assembled.

21. **Rivets, Rivet Holes, Riveting, and Bolts.**—Size of rivets as designated on plans shall be understood to mean the actual size of the cold rivet before heating.

Pitch of rivets shall not be less than three times the diameter of the rivet, nor greater than 6 inches or 16 times the thickness of the thinnest outside section. All punching shall be accurately done. Drifting to enlarge unfair holes will not be allowed. If the holes must be enlarged to admit the rivet, they shall be reamed. Poor matching up of holes will be cause for rejection.

When general reaming is not required the diameter of the punch shall not be more than $\frac{1}{16}$ inch greater than the diameter of the rivet, nor the diameter of the die more than $\frac{1}{8}$ inch greater than the diameter of the punch. Material more than $\frac{3}{4}$ inch thick shall be subpunched and reamed, or drilled from the solid. Riveted members shall have all parts well pinned up and firmly drawn together with bolts before riveting is commenced. Rivets shall be given by pressure tools whenever possible, and pneumatic hammers shall be used in preference to hand driving.

Completed rivets shall look neat and finished, with heads of approved shape, full, and of equal size. They shall be central on shank and grip the assembled pieces firmly. Recupping and calking will not be allowed. Loose, burned, or otherwise defective rivets shall be cut out and replaced. In cutting out rivets great care shall be taken not to injure the adjacent metal. If necessary, they shall be drilled out.

Whenever bolts are used in place of rivets which transmit shear or when used in compression members, the holes shall be reamed parallel and the bolts turned to a driving fit. A washer not less than $\frac{3}{16}$ inch thick shall be used under nut.

22. **Reamed Work.**—When reaming is required by the contract, the punch used shall have a diameter not less than $\frac{3}{16}$ inch smaller than the nominal diameter of the rivet. Reaming shall be done after the pieces forming one built member are assembled and firmly bolted together, using twist drills having diameter $\frac{1}{16}$ inch larger than the nominal diameter of the rivet. Outside burrs on reamed holes shall be removed.

23. **Eye-bars.**—Eye-bars shall be straight and true to size, and shall be free from twists, folds in the neck or head, or any other defect. Heads shall be made by upsetting, rolling, or forging. Welding will not be allowed. The form of heads will be determined by dies in use at the works where the eye-bars are made, if satisfactory to the inspector; but the manufacturer shall guarantee the bars to break in the body when tested to rupture. The thickness of head and neck shall not vary more than $\frac{1}{16}$ inch from that specified.

Before boring, each eye-bar shall be properly annealed and carefully straightened. Pinholes shall be in the center line of bars and in the center of the heads. Bars of the same length shall be bored so accurately that, when placed together, pins $\frac{1}{32}$ inch smaller in diameter than the pinholes can be passed through the holes at both ends of the bars at the same time without forcing.

24. **Shop Paint and Painting.**—All steel work, except reinforcement steel for concrete, shall be given one coat of paint before leaving the shop.

It shall be cleaned of all moisture, scale, rust, grease, dirt, chips, and other foreign matter before being painted.

Surfaces coming in contact shall be cleaned and given one coat of paint on each surface before assembling.

Parts not accessible for painting after erection, but not in riveted contact, shall be given a second coat of paint at the shop. The first coat must be dry before the second coat is applied.

No painting shall be done in wet or freezing weather except under cover.

Machine-finished surfaces shall be coated with white lead and tallow before being exposed to the weather.

Paint for shop coats shall be composed of red lead, white zinc, raw linseed oil, and turpentine Japan drier, mixed in proportions of 100 pounds of lead, 20 pounds of zinc, 5 gallons of oil, and $3\frac{3}{4}$ pints of drier.

Paint shall be freshly mixed in small quantities and be well stirred before using.

The Navy standard specifications for paint material shall be adhered to so far as applicable.

25. **Shop Inspection.**—The manufacturer shall furnish all facilities for inspecting and testing the weight and quality of workmanship at the shop where material is manufactured.

Shop inspection will be made by an inspector assigned by the Bureau of Yards and Docks, unless such inspection shall not be considered warranted by the bureau because of the location, magnitude, or the character of the work, in which case inspection for workmanship will be made by the officer in charge at the place of erection.

The inspector shall have full access at all times to all parts of the shop where material under his inspection is being manufactured.

The inspector may stamp each piece which is accepted with a private mark.

It shall be distinctly understood that shop inspection shall not operate in any manner to relieve the manufacturer from full responsibility for the accuracy and character of the work in all of its details, and that errors or faults which may be discovered after delivery or during erection shall be satisfactorily corrected by the manufacturer in accordance with the requirements of the contract and without any increase in the contract price.

26. **Loading and Shipping Invoices.**—Material shall be so prepared for shipment and be so loaded that it will suffer no distortion or damage during transportation. Complete copies of shipping invoices for each shipment in triplicate shall be furnished

the inspector or be forwarded to the Bureau of Yards and Docks in case there has been no inspector detailed.

## FIELD WORK

27. **Unloading, Storing, and Handling.**—Material shall be unloaded, stored, and handled in such manner and with such appliances and care as to prevent distortion and injury of the members. Material which is injured shall be replaced if necessary, as may be required by the officer in charge, and at the expense of the contractor.

28. **Erecting.**—All field connections shall be riveted. The various members forming part of a completed frame or structure after being assembled shall be accurately aligned and adjusted before riveting is begun. All requirements specified for shopwork which are applicable shall apply to field work.

29. **Painting Steel Work After Erection.**—Steel for reinforcing concrete shall not be painted.

Surfaces which are to remain in free contact with air, but which are to be covered in or incased by brickwork, fireproofing, or framing, shall be given two coats of paint.

All surfaces which are to remain exposed upon the completion of the structure, both exterior and interior, shall be given two coats of paint.

Surfaces which have been chafed or imperfectly covered shall be properly retouched and allowed to dry before applying any final coat of paint.

Freshly painted surfaces shall be allowed to dry before being enclosed.

After erection, the heads of field rivets and parts where the paint has been rubbed off in transportation or during erection shall be repainted. The painting of the field rivet heads shall be done promptly after their acceptance. The rivets shall be cleaned of all mill scale before painting.

Both coats of paint used for finishing exposed surfaces shall be composed of white lead, white zinc not greater than 50 per cent, and boiled linseed oil, which conform to the requirements of the latest specifications for the same issued by the Navy Department, mixed in proportions and colored to the satisfaction of the officer in charge.

Paint used for enclosed surfaces shall be the same as required for shop coat.

Painting shall be done only at such times as may be approved by the officer in charge and subject to the same restrictions as to weather and preparation of surfaces as specified for shop coats.

Succeeding coats of paint shall be mixed so as to vary somewhat in color in order that there may be no confusion as to the surfaces which have been painted.

30. **Steel Reinforcement for Concrete.**—Steel shall be stored under shelter. It shall be cleaned of all loose scale, oil, grease, and dirt before being embedded and shall be secured in place to the satisfaction of the officer in charge.

# SPECIAL-TREATMENT STEEL PLATES FOR PROTECTIVE HULL PLATING

## NAVY DEPARTMENT

1. **General Test.**—"Specifications for the Inspection of Steel and Iron Material (General Specifications, Appendix I)," issued by the Navy Department (C. and R.), June, 1912, form a part of these specifications and must be complied with in all respects.

2. **Requirements for Protective Deck Plates.**—Plates for protective decks and for similar uses shall be furnished in accordance with the following requirements.

3. **Heat Treatment.**—All tests are to be made after heat treatment.

4. **Statement as to Heat Temperature.**—The manufacturer shall furnish a statement showing to what temperature each plate may be subjected in working without risk of diminishing its ballistic qualities.

5. **Test Pieces.**—(a) When Rolled.—From each plate there shall be taken two specimens cut in the direction of rolling—one for tensile and one for bending. Location of the test pieces shall be determined by the inspector, but shall not be such as to interfere with cutting the plate to its proper size.

(b) When Forged.—From each plate there shall be taken three specimens cut in a longitudinal direction, two of these to be for tensile tests and one for bending.

One tensile test specimen shall be taken from each end of the plate.

Tensile specimens shall be standard 2-inch type.

Bending test specimens shall be ½ inch square.

6. **Tensile Test.**—The tensile test for plates under 120 pounds shall show a yield point of not less than 105,000 pounds per square inch; an ultimate tensile strength not less than 120,000 pounds per square inch, and an elongation in 2 inches of not less than 17 per cent. For plates 120 pounds and above, the tensile test shall show a yield point of not less than 95,000 pounds per square inch, an ultimate tensile strength not less than 112,000 pounds per square inch, an elongation in 2 inches of not less than 20 per cent.

7. **Bending Test.**—The specimens for bending test shall be bent cold through an angle of 180° over a diameter equal to the thickness of the specimen without fracture.

8. **Chemical Analysis.**—The chemical composition shall be determined from time to time, and shall show reasonable uniformity.

9. **Ballistic Tests.**—The inspector shall select at least one plate for each 250 tons of material manufactured, the plates to be selected with a view to representing the various gauges that may be ordered, and these shall be subjected to ballistic test at the Naval Proving Ground, Indian Head, Md. Where small or miscellaneous orders for protective material are involved, one plate may be selected or ballistic test waived at the option of the bureau. Such plates as may be required for ballistic test shall be delivered at the Proving Ground without expense to the Government, and these plates shall become the property of the Government if they pass the test. Plates that fail remain the property of the manufacturer.

Test plates must be at least 54 inches wide, and will be attacked at the angle specified below. They will be supported on edge by clamps securing them to two horizontal backing pieces whose nearest edges will not be less than 36 inches apart.

10. **Shell Tests.**—One round of uncapped shell will be fired at each plate using the following caliber and estimate striking velocity of projectile:

| Weight of Plate per Square Foot | Caliber | Estimated Striking Velocity | Angle of Attack | Weight of Plate per Square Foot | Caliber | Estimated Striking Velocity | Angle of Attack |
|---|---|---|---|---|---|---|---|
| *Pounds* | *Inches* | *Feet-Seconds* | | *Pounds* | *Inches* | *Feet-Seconds* | |
| 40 | 6 | 1,330 | 9 | 120 | 8 | 2,020 | 15 |
| 60 | 6 | 1,910 | 9 | 160 | 12 | 1,490 | 15 |
| 80 | 8 | 1,695 | 9 | 200 | 12 | 1,875 | 15 |
| 100 | 8 | 2,170 | 9 | 200 | 14 | 1,480 | 15 |

Plates up to and including those weighing 70 pounds per square foot will be tested with a 6-inch projectile; plates above 70 pounds up to 140 pounds will be tested with an 8-inch projectile; plates above 140 pounds up to 200 pounds will be tested with a 12-inch projectile.

For thickness of plates other than the above, the square of the test velocity is to be obtained by interpolating between the squares of the velocities given in the table.

If the plate is not pierced and develops no through cracks, the test will be considered satisfactory. If the plate is not pierced but develops a small amount of through cracks, the Bureau of Construction and Repair will then consider the characteristics of the plate, as shown by the several tests to which it has been subjected, and after such consideration may accept or reject the material represented by the plate or make such additional tests as may be deemed necessary.

For thickness of plates other than the above, the square of the test velocity is to be obtained by interpolating between the squares of the velocities given in the table.

If the plate is not pierced and develops no through cracks, the test will be considered satisfactory. If the plate is not pierced but develops a small amount of through cracks, the Bureau of Construction and Repair will then consider the characteristics of the plate, as shown by the several tests to which it has been subjected and, after such consideration, may accept or reject the material represented by the plate or make such additional tests as may be deemed necessary.

11. **Weight Tolerance.**—Plates of special-treatment steel may be accepted:

(a) When Rolled, if they vary between the specified weights and 2 per cent above or 3 per cent below the weights as estimated from the ordered dimensions.

(b) When Forged, if thickness at edges does not vary more than $\frac{1}{8}$ inch above or $\frac{1}{4}$ inch below the nominal thickness ordered, and if thickness inside the edges is in no place less than $\frac{1}{4}$ inch below or $\frac{1}{8}$ inch above the thickness ordered. Edges whose upper limits exceed the amount allowed shall be ground down to the nominal thickness ordered, for a distance extending not less than 3 inches back from edges, when directed by the inspector.

# DRILL ROD STEEL

## NAVY DEPARTMENT

The material shall be known as "Drill Rod Steel," and shall conform to the following analysis:

| | Per Cent Limit |
|---|---|
| Carbon | 1.25 to 1.15 |
| Chromium | Optional. |
| Manganese | .35 to .15 |
| Phosphorus | .015 to .00 |
| Silicon | .40 to .10 |
| Sulphur | .02 to .00 |
| Vanadium | Optional. |
| Iron | Remainder. |

The rods shall be smooth and polished, or unpolished, as specified, and cut to lengths as ordered, and shall have smooth ends and be in strict accordance with the sizes called for. A variation of more than 0.0005 inch on sizes $\frac{7}{16}$ inch in diameter or less and 0.001 inch on sizes larger than $\frac{7}{16}$ inch shall be sufficient cause for rejection of the rods showing such variation.

A sample rod will be selected at random from each of the sizes ordered, and after proper treatment shall be given a thorough practical test, and must prove equal in all respects to rods of similar analysis in Government stock.

# HOT-ROLLED OR FORGED CARBON STEEL

(For Use by the Naval Gun Factory)

NAVY DEPARTMENT

1. **General Instructions.**—The general specifications for the inspection of material, issued by the Navy Department, and the requisitions for the material shall form a part of these specifications.

2. **Method of Manufacture.**—Carbon steel bought under this specification must be manufactured by the crucible or open-hearth process, depending on which process is specified in the requisition. This material shall be delivered in the annealed condition.

3. **Slabs, Blooms, and Billets.**—Contractors must satisfy the Government that all slabs, blooms, billets, or other forgings of carbon steel have been rolled or forged from ingots whose cross-section is at least four times that of the finished slab, bloom, or billet, and from ingots from which a discard of at least 5 per cent of the total weight has been taken from the bottom and 30 per cent from the top, if top poured; and 5 per cent from the bottom and 20 per cent from the top, if the ingot has been bottom poured or fluid compressed.

4. **Surface Inspection.**—All slabs, blooms, billets, or forgings of any kind bought under this specification must be free from cracks, seams, slivers, flaws, or other injurious imperfections and must have a workmanlike finish and must conform with the dimensions given on the drawing or in the requisition, to within the tolerance specified.

5. **Rejection of Defective Material.**—Material may be rejected at the place of delivery for defects which were not manifest upon original inspection, but develop during the process of forging or machining. In such cases the manufacturer must make good any material rejected. This liability on the part of the contractor to expire six months after the delivery of the material in question, except in special cases where certain material has been provisionally accepted with the understanding that its final acceptance depends on certain conditions which have been mutually agreed upon by the contractor and the Government.

6. **Chemical Composition.**—The various classes of carbon steel are to conform to the chemical composition given in the following table:

| Identification (Class) | Carbon | | Manganese | | Phosphorus | Sulphur |
|---|---|---|---|---|---|---|
| | Limits | Desired | Limits | Desired | Not to Exceed— | Not to Exceed— |
| | *Per Cent* | *Per Ct.* | *Per Cent* | *Per Ct.* | *Per Ct.* | *Per Ct.* |
| C–10. . . . . . . . . | 1.05 to 0.90 | 0.95 | 0.50 to 0.25 | 0.35 | 0.025 | 0.025 |
| C–8. . . . . . . . . . | .90 to .75 | .80 | .50 to .25 | .35 | .025 | .025 |
| C–6. . . . . . . . . . | .65 to .55 | .60 | .80 to .50 | .65 | .04 | .04 |
| C–5. . . . . . . . . . | .55 to .45 | .50 | .80 to .50 | .65 | .04 | .04 |
| C–4. . . . . . . . . . | .45 to .35 | .40 | .80 to .50 | .65 | .04 | .04 |
| C–3. . . . . . . . . . | .35 to .25 | .30 | .80 to .50 | .65 | .04 | .04 |
| C–2. . . . . . . . . . | .25 to .15 | .20 | .80 to .50 | .65 | .04 | .04 |
| C–1. . . . . . . . . . | .15 to .05 | .10 | Not to exceed 0.60 | . . . . | .04 | .04 |

# COLD-ROLLED OR COLD-DRAWN MACHINERY STEEL RODS AND BARS

## NAVY DEPARTMENT

1. **General Instructions.**—The "General Specifications for Inspection of Steel and Iron Material, General Specifications, Appendix I," issued by the Navy Department (C. and R.), June, 1912, shall form a part of these specifications, and must be complied with as to material, method of inspection, and all other requirements therein.

2. **Physical and Chemical Requirements.**—(a) All material shall be free from injurious defects and have a smooth and workmanlike finish.

(b) The physical and chemical requirements of cold-rolled or cold-drawn steel shall be in accordance with the following table:

| | Ultimate Tensile Strength | Minimum Elastic Limit | Types of Test Pieces | Minimum Elongation |
|---|---|---|---|---|
| | *Pounds per Square Inch* | *Per Ct.* | | *Per Ct.* |
| Under ¼ inch in diameter or thickness | ... | ... | ... | ... |
| ¼ inch to ½ inch inclusive, in diameter or thickness | 80,000–110,000 | 75 Ult. | 3 | 8 in 8″ |
| Over ½ inch to 1½ inches, inclusive, in diameter or thickness | | | 3 | 12 in 2″ |
| | 75,000–100,000 | 75 Ult. | 3 | 10 |
| | | | 1 | 16 |
| Over 1½ inches in diameter or thickness | 70,000– 90,000 | 70 Ult. | 3 | 14 |
| | | | 1 | 18 |

| | Maximum Amount of— | | Cold Bend |
|---|---|---|---|
| | P | S | |
| | *Per Ct.* | *Per Ct.* | |
| Under ¼ inch in diameter or thickness | 0.06 | 0.06 | 180° to 3 diam. |
| ¼ inch to ½ inch inclusive, in diameter or thickness | .06 | .06 | 180° to 3 diam. |
| Over ½ inch to 1½ inches, inclusive, in diameter or thickness | .06 | .06 | 180° to 3 diam. |
| Over 1½ inches in diameter or thickness | .06 | .06 | 180° to 3 diam. |

**Elongation: For type 3 test pieces, measure in 8 inches except for sizes ½ inch and less, for which elongation may be measured in 2 inches.**
**For type 1 test pieces, measure in 2 inches.**

3. **Tests.**—For test purposes each melt of material submitted shall be grouped into lots conforming to the sizes specified in the above table. For material 1½ inches diameter and under, two test specimens, one for tensile and one for bending, shall be taken, both from the smallest and from the largest sizes in each lot submitted. Over 1½ inches diameter, tensile and bending test specimens shall be taken from each size of each melt submitted for inspection. Type 1 test pieces and bending test specimens shall be taken as nearly as possible at a distance from the longitudinal axis of the bar equal to one-quarter of the diameter.

4. **Steel Cold-Rolled or Cold-Drawn.**—Steel may be cold-rolled or cold-drawn at

the option of the manufacturer, and rods or bars shall be reduced from the hot-rolled state, by either process, about $\frac{1}{32}$ inch in diameter or thickness and width for rods or bars up to a finished diameter or thickness of $\frac{1}{2}$ inch. For rods or bars greater in finished diameter or thickness than $\frac{1}{2}$ inch, a reduction in diameter or thickness and width of not less than $\frac{1}{16}$ inch shall be required. The following variation in the finished diameter or thickness and width is permissible:

| Size | Allowable Variation |
|---|---|
| | *Inch* |
| Up to and including 1 inch | 0.003 |
| Above 1 inch and including $2\frac{1}{2}$ inches | .004 |
| Above $2\frac{1}{2}$ inches | .005 |

# EXTRA SOFT STEEL FOR USE AS A WROUGHT-IRON SUBSTITUTE

## NAVY DEPARTMENT

1. **Quality.**—The material shall be known as extra soft steel and shall be used wherever in the opinion of the officer concerned it can be used to greater advantage than wrought iron. This material should not contain more than $\frac{4}{100}$ of 1 per cent of phosphorus, not more than $\frac{4}{100}$ of 1 per cent of sulphur, and not more than $\frac{12}{100}$ of 1 per cent of carbon.

2. **Test Pieces.**—Two test specimens, one for tensile and one for bending test, shall be taken as specified below, the classification being based on size (diameter or thickness) of material.

(a) Up to and including $\frac{1}{4}$ inch.

(b) From $\frac{1}{4}$ inch up to and including $\frac{1}{2}$ inch.

(c) From $\frac{1}{2}$ inch up to and including $1\frac{1}{2}$ inches.

(d) For all sizes over $1\frac{1}{2}$ inches, two test pieces shall be taken for each size.

Whenever the material offered represents more than one heat, the material from each heat shall for test purposes be considered a separate lot, and shall be so tested. The two test specimens provided for shall be taken, if possible, from different sizes included in the class; not more than one test specimen shall be taken from any one bar.

3. **Tensile Strength, Elastic Limit, Elongation, Contraction of Area.**—The test specimens must show a tensile strength of not less than 45,000 pounds nor more than 55,000 pounds per square inch, and an elongation of not less than 28 per cent, a contraction in area of not less than 48 per cent, and an elastic limit of not less than one-half the ultimate strength. The elongation for rods or bars $\frac{1}{2}$ inch or less in diameter or thickness will be measured on a length equal to 8 times the diameter or thickness of section tested; for sections over $\frac{1}{2}$ inch and less than $\frac{3}{4}$ inch in diameter or thickness the elongation will be measured on a length of 6 inches; above $\frac{3}{4}$ inch in diameter or thickness the elongation will be taken on a length of 8 inches.

4. **Bending at the Weld.**—Each class of material (size, classification paragraph 2) in each heat shall be tested for bending at the weld as follows: The bending specimen provided for in paragraph 2 shall be cut in two pieces which shall then be scarf welded together. After welding and subjecting to cold-bending tests at the center of the weld, the specimen shall show no cracks or flaws on the outer curves of the bends upon being bent flat to 180°.

# STEEL RODS AND BARS FOR STANCHIONS, DAVITS, AND DROP AND MISCELLANEOUS FORGINGS

## NAVY DEPARTMENT

1. **General Instructions.**—"Specifications for the Inspection of Steel and Iron Material, General Specifications, Appendix I," issued June, 1912, shall form a part of these specifications and must be complied with in all respects.

2. **Physical and Chemical Requirements.**—The material shall be free from injurious defects and shall have a workmanlike finish.

The physical and chemical requirements are to be in accordance with the following table:

| Class | Material | Size | Minimum Tensile Strength | Minimum Elongation | Maximum Amount of— | |
|---|---|---|---|---|---|---|
| | | | | | P | S |
| | | | *Pounds per Square Inch* | | *Per Cent* | *Per Cent* |
| Med. steel.. | Open-hearth carbon steel | 1½ inches diameter or thickness or less. | 58,000 | 28 per cent in 8 inches (Type 3 test piece to be used). | 0.04 | 0.045 |
| | | Above 1½ inches in diameter or thickness. | 60,000 | 30 per cent in 2 inches (Type 1 test piece to be used). | .04 | .045 |

(a) Elongation.—For rounds, squares, or hexagons ½ inch or less in thickness or diameter, the elongation will be measured on a length equal to eight times the thickness or diameter of section tested; for sections over ½ inch and less than ¾ inch in thickness or diameter the elongation will be taken on a length of 6 inches. For flat bars less than ¼ inch in thickness, the elongation will be measured on a length equal to 24 times the thickness. In the preceding cases the required percentage of elongation shall be that specified for the Type No. 3 test piece.

3. **Finished Material.**—The material shall be free from all injurious defects and shall have a workmanlike finish. All bars must be true to section; round bars must have practically perfect circular section and any considerable difference in the largest and smallest diameter of a bar will be sufficient cause for rejection. All bars must be straight and out of wind.

4. **Tensile Tests.**—From each melt and size and (if annealed) from each furnace charge there shall be taken from different objects, if practicable, and from material uppermost in the ingot, two specimens for tensile test. In case it is not practicable to identify in the finished object the material uppermost in the ingot, the inspector will take a sufficient number of additional tests to satisfy himself fully as to the uniformity of the material.

5. **Bending Tests.**—Two specimens for making cold-bending tests shall be selected in the same manner as prescribed for the specimens selected for tensile tests. These cold-bend specimens shall be bent over flat on themselves without showing any cracks or flaws on the convex surface of the bend.

6. **Tolerances.**—

STANDARD ALLOWABLE VARIATIONS IN THE SIZES OF HOT-ROLLED BARS

(a) Rounds, squares, and hexagons

| Variation in Size | Under | Over |
|---|---|---|
| | *Inch* | *Inch* |
| Up to and including ½ inch | 0.007 | 0.007 |
| Over ½ inch up to and including 1 inch | .010 | .010 |
| Over 1 inch up to and including 2 inches | .016 | .031 |
| Over 2 inches up to and including 3 inches | .031 | .047 |
| Over 3 inches up to and including 5 inches | .031 | .094 |
| Over 5 inches up to and including 8 inches | .063 | .125 |

(b) Flats

| Width of Flats | Variation in Width | | Variation in Thickness, Under and Over Thickness of Flats | | | |
|---|---|---|---|---|---|---|
| | Under | Over | $\frac{3}{16}$ Inch and Under | Over $\frac{3}{16}$ Inch up to ½ Inch | Over ½ Inch up to 1 Inch | Over 1 Inch up to 2 Inches |
| | *Inch* | *Inch* | *Inch* | *Inch* | *Inch* | *Inch* |
| Up to and including 1 inch | 0.016 | 0.031 | 0.006 | 0.008 | 0.010 | 0.031 |
| For 1 inch up to and including 2 inches | .031 | .047 | .008 | .012 | .016 | .031 |
| For 2 inches up to and including 4 inches | .047 | .063 | .010 | .015 | .020 | .031 |
| For 4 inches up to and including 6 inches | .063 | .094 | .010 | .015 | .020 | .031 |

# SPRING STEEL

## NAVY DEPARTMENT

1. **General Instructions.**—The "General Specifications for Inspection of Steel and Iron Material, General Specifications, Appendix I," issued by the Navy Department (C. & R.) June, 1912, shall form a part of these specifications, and must be complied with as to material, method of inspection, and all other requirements therein.

2. **Process of Manufacture.**—Spring steel shall be manufactured by either the open-hearth or crucible process.

3. **Chemical Requirements.**—Chemical properties of spring steel shall be in accordance with the following table:

| Carbon, per Cent | Manganese, per Cent | Silicon, per Cent | Other Alloys | Phosphorus, per Cent | Sulphur, per Cent |
|---|---|---|---|---|---|
| Not less than 0.70; not more than 1.10 | Not less than 0.25; not more than 0.50 | Not over 0.25 | (See note) | Not over 0.05 | Not over 0.05 |

NOTE.—Vanadium or other elements may be used to obtain the necessary physical characteristics.

4. **Physical Requirements.**—From each lot of twenty bars, or fraction thereof of the same size, made from the same open-hearth melt or crucible furnace charge, three bars will be selected at random and subjected to tests as described below. Bars that do not vary in their cross-sectional dimensions more than $\frac{1}{8}$ inch will be considered of one size. The nick test and deflection test will be made with the full-size specimen. Tensile tests will be made with the full-size specimen when practicable; when not practicable "Type No. 1" test piece will be allowed. Each test specimen will be taken from a different bar.

(a) TENSILE TESTS.—A specimen bar after being tempered shall have an ultimate tensile strength of at least 180,000 pounds per square inch, with an elastic limit of at least 75 per cent of the ultimate tensile strength.

(b) NICK TEST.—A specimen when nicked and broken shall present a fine, uniform grain.

(c) DEFLECTION TEST.—A specimen bar after being tempered, resting upon supports 24 inches between centers, shall not take a permanent set of more than 0.05 inch after the first application of a load corresponding to a fiber stress of 135,000 pounds per square inch, nor a permanent set of more than 7.5 per cent of the total deflection under a load producing a fiber stress of 160,000 pounds per square inch, nor any further set after five additional applications of a load giving a fiber stress of 150,000 pounds per square inch.

5. **Surface Defects.**—Spring steel shall be free from all injurious defects. The bars shall be thoroughly cleaned by pickling or other approved method.

6. **Tolerances.**—In the case of round bars a variation of 0.02 inch in diameter is allowable. In the case of rectangular bars an allowance of 0.02 inch in thickness and 0.03 inch in width from the sizes ordered will be allowed.

# TOOL STEEL

## NAVY DEPARTMENT

### Chemical Composition

| Tungsten Tool Steel | Class 1, per Cent Limit | | Class 2, per Cent Limit | |
|---|---|---|---|---|
| | Maximum | Minimum | Maximum | Minimum |
| Carbon | 0.75 | 0.55 | 1.50 | 1.35 |
| Chromium | 5.00 | 2.50 | .00 | .00 |
| Manganese | .30 | .05 | .20 | .10 |
| Phosphorus | .015 | .00 | .015 | .00 |
| Silicon | .30 | .00 | .20 | .00 |
| Sulphur | .02 | .00 | .02 | .00 |
| Tungsten | 20.00 | 16.00 | 3.50 | 2.00 |
| Vanadium | 1.50 | .35 | (2) | (2) |
| Iron | (1) | (1) | (1) | (1) |

| Carbon Tool Steel | Class 1, per Cent Limit | | Class 2, per Cent Limit | |
|---|---|---|---|---|
| | Maximum | Minimum | Maximum | Minimum |
| Carbon | 1.25 | 1.15 | 1.15 | 1.05 |
| Manganese | .35 | .15 | .35 | .15 |
| Nickel | ..... | .10 | .00 | .00 |
| Phosphorus | .015 | .00 | .015 | .00 |
| Silicon | .40 | .10 | .40 | .10 |
| Sulphur | .02 | .00 | .02 | .00 |
| Tungsten | .00 | .00 | .00 | .00 |
| Iron | (1) | (1) | (1) | (1) |

| Carbon Tool Steel | Class 3, per Cent Limit | | Class 4, per Cent Limit | |
|---|---|---|---|---|
| | Maximum | Minimum | Maximum | Minimum |
| Carbon | 0.95 | 0.85 | 0.85 | 0.75 |
| Manganese | .35 | .15 | .35 | .15 |
| Nickel | .00 | .00 | .00 | .00 |
| Phosphorus | .02 | .00 | .02 | .00 |
| Silicon | .40 | .10 | .40 | .10 |
| Sulphur | .02 | .00 | .025 | .00 |
| Tungsten | (2) | (2) | .00 | .00 |
| Iron | (1) | (1) | (1) | (1) |

[1] Remainder. [2] Optional.

## PHYSICAL TESTS

1. **Tungsten Tool Steel.**—Class 1.—The sample bar will be forged into five tools, treated and ground to the No. 30 form of the Sellers system of lathe tool forms. Each tool will be tested on a nickel-steel forging of about 100,000 pounds tensile strength, with a cut $\frac{3}{16}$ inch deep, 0.044 inch feed, and a cutting speed of 65 feet per minute. Each tool will be twice reground and retested. A record will be made of the length of time each tool cuts without a lubricant or cutting compound before it is ruined.

2. Class 2.—Five $\frac{7}{16}$-inch diameter 4-tooth facing mills will be made from the sample rod and tested on a piece of $\frac{5}{8}$-inch ship's plate without lubricant. Each mill will be run until it is so dull that it breaks either in the teeth or in the shank. The depth of cut will be 0.08 inch, the revolutions per minute of the mill will be 370 and the feed of material 20 inches per minute. A record will be made of the length of time each mill operates.

3. **Carbon Tool Steel.**—Class 1.—Five $\frac{7}{16}$-inch diameter 4-tooth facing mills will be made from the sample rod and tested on a piece of $\frac{5}{8}$-inch ship's plate without lubricant. Each mill will be run until it is so dull that it breaks either in the teeth or in the shank. The depth of cut will be 0.08 inch, the revolutions per minute of the mill will be 370 and the feed of material 20 inches per minute. A record will be made of the length of time each mill operates.

4. Class 2.—Five $\frac{7}{16}$-inch diameter 4-tooth facing mills will be made from the sample rod and tested on a piece of $\frac{5}{8}$-inch ship's plate without lubricant. Each mill will be run until it is so dull that it breaks either in the teeth or in the shank. The depth of cut will be 0.08 inch, the revolutions per minute of the mill will be 370, and the feed of material 20 inches per minute. A record will be made of the length of time each mill operates.

5. Class 3.—Five $\frac{1}{2}$-inch pneumatic chisels will be made from the sample bar. Each chisel will be tested on a nickel-steel plate with a cut $\frac{1}{16}$ inch deep. A record will be made of the distance each chisel cuts with a lubricant before it is ruined.

6. Class 4.—Two $\frac{1}{2}$-inch rivet sets will be made from the sample bar. A record will be made of the condition of the sets after a certain number of rivets have been driven.

7. **Modification of Tests.**—Any or all of the above tests may be modified at the discretion of the Engineer officer.

## GENERAL

8. **Method of Manufacture.**—The tool steels must be made in either the electric or crucible fornace, and must be of homogeneous composition. The bars or rods shall be forged or rolled accurately to the dimensions specified, and must be free from seams, checks, and other physical defects. They must be delivered annealed and, unless otherwise specified, in commercial lengths. Short pieces will not be accepted. Drill rods must be coated with a rust preventive.

9. **Stamps on Material.**—Each bar or rod of tool steel, excepting drill rods, whether sample for "selective test" or material delivered under contract, shall be legibly stamped with the manufacturer's name, his trade name, heat number, and temper index of the tool steel, also the classification stamps as given in these specifications. The tungsten tool steels, Classes 1 and 2, shall be stamped "T-1" and "T-2," respectively, and the carbon tool steels, Classes 1, 2, 3, and 4, "C-1," "C-2," "C-3," and "C-4," respectively. The letters and figures of these classification stamps should be about $\frac{3}{16}$ inch high. If the bars or rods are longer than about 4 feet and larger than $\frac{5}{8}$ inch diameter, square, hexagon, octagon, etc., the above stamps should be placed at intervals of about 3 feet along the bar. On bars $\frac{5}{8}$ inch diameter and smaller, square, hexagon, octagon, etc., the above stamps should be placed on one end only. Each drill rod shall be stamped with the tool-steel classification stamp only on one end, and the stamp for the identification of heat number on the other end.

10. **Acceptance Test.**—Samples for chemical analyses for "acceptance test" will be taken from the material delivered by the contractor to the general storekeeper, navy yard, Philadelphia, Pa., or if the material is inspected at place of manufacture, the inspector will forward samples for chemical analysis to the general storekeeper, navy yard, Philadelphia, Pa., who will forward them to the engineer officer for him to arrange for the analyses and recommend the acceptance or rejection of the material. If the analysis proves that the composition of the material does not correspond to that of the sample bar or rod submitted for "selective test," or if the sulphur or phosphorus content exceeds the specification limits, the material will be rejected. Physical tests similar to the "selective test" may also be made, at the discretion of the Engineer

officer. The contractor shall replace the rejected shipment within two weeks, if practicable, after receipt of notice of rejection.

11. **Place of Manufacture.**—Bidders must state in their proposals, on the blank lines provided under each class, the name of the manufacturer, as well as the place where the material will be manufactured, giving the exact address.

If this information can not be furnished in his bid, the contractor must, within five days after receipt of notice of award, furnish the Bureau of Steam Engineering with the foregoing information.

All handling of material necessary for purposes of inspection shall be performed and all test specimens necessary for the determination of the qualities of material used shall be prepared and tested at the expense of the contractor.

If inspection is authorized at the place of manufacture, shipment made without authority from the Government inspector may result in return, at contractor's expense, of material to place of manufacture for inspection.

If contract is sublet, the contractor shall furnish the Bureau of Steam Engineering with four copies of his order to the subcontractor for comparison with the specifications of the contract.

In connection with the inspection of the material, if incorrect information is given, thereby causing one or more useless trips by the inspectors, the Government reserves the right to charge the expense of such useless trips to the contractor, and further inspection at the mills may be denied the contractor at the option of the bureau.

12. **Defective Material.**—If material, when being manufactured into tools, develops physical defects which could not be detected by inspection, such as "cracks," "pipes," etc., the manufacturer of this steel shall replace, without cost to the Government, such defective material.

## PROPOSALS

13. **Reservation and Alternate Proposals.**—The right is reserved to reject any or all proposals.

Bidders may submit proposals on tool steel which differs from the composition and method of manufacture specified, provided this is clearly stated in their proposals, and provided they furnish the engineer officer with a statement of the exact chemical composition and method of manufacture of the tool steel. This information will be considered confidential by the engineer officer if the bidder requests it. The tool steel will be tested if, in the opinion of the engineer officer, it is considered suitable for the purpose intended.

14. **Selective Test.**—Each bidder shall furnish with his proposal sample bars of tool steel, stamped as called for under heading "Stamps on Material," for the "selective test." The relation of the results obtained from the tests conducted as provided for under the heading "Physical Tests" and the price of the material determine the selective factor. The dimensions of the sample bars shall be as follows:

Tungsten tool steel:

CLASS 1.—$\frac{1}{2}$ by 1 inch by 5 feet long.

CLASS 2.—$\frac{11}{16}$-inch diameter rod, $2\frac{1}{2}$ feet long.

Carbon tool steel:

CLASS 1.—$\frac{11}{16}$-inch diameter rod, $2\frac{1}{2}$ feet long.

CLASS 2.—$\frac{11}{16}$-inch diameter rod, $2\frac{1}{2}$ feet long.

CLASS 3.—$\frac{3}{4}$-inch octagon rod, 5 feet long.

CLASS 4—2-inch diameter rod, 2 feet long.

15. **Treatment of Samples.**—Each bidder will state in his proposal, if he considers it necessary to do so, the treatment to which the material must be subjected in order to get, in his opinion, the best results.

16. **Delivery of Sample Bars.**—All sample bars, stamped as called for under the heading "Stamps on Material," must be delivered to the General Storekeeper, Building No. 4, Navy Yard, Philadelphia, Pa., prior to the time fixed for opening of proposals. Sample bars delivered late will not be received. Failure to comply with the above requirements will eliminate the proposal from consideration. All sample bars will be

delivered by the general storekeeper to the Engineer officer for him to conduct the "selective tests."

17. **Award of Contract.**—The Engineer officer will, after the prescribed tests have been made, recommend the award of contract for the tool steel or tool steels which, in his opinion, it is to the best interest of the Government to purchase. The selective factor will be the basis for selection.

18. **Intermediate Sizes.**—Intermediate sizes not specified when required will be ordered and paid for at the price of the next higher size.

## PURPOSE FOR WHICH THE STEEL IS INTENDED

19. **Tungsten Tool Steel.**—Class 1.—Drill rods, lathe and planer tools, milling-machine tools, and in general all tools for which high-speed steel is used.

20. Class 2.—Lathe and planer tools and general machine-shop tools which require a keen and durable cutting edge.

21. **Carbon Tool Steel.**—Class 1.—Drill rods, lathe, and planer tools, and tools requiring keen-cutting edge combined with great hardness, such as drills, taps, reamers, and screw-cutting dies.

22. Class 2.—Milling cutters, mandrels, trimmer dies, threading dies, and general machine-shop tools requiring a keen-cutting edge combined with hardness.

23. Class 3.—Pneumatic chisels, punches, shear blades, etc., and in general tools requiring hard surface with considerable tenacity.

24. Class 4.—Rivet sets, hammers, cupping tools, smith tools, hot drop-forge dies, etc., and in general tools which require great toughness combined with the necessary hardness.

## FIRE CLAYS AND FIRE BRICKS

The testing of clay refractories, with special reference to their load-carrying capacity at furnace temperatures, by A. V. Bleninger and G. H. Brown, form the subject matter of Technologic Paper No. 7 of the Bureau of Standards.

From the results of the work done by the above chemists in the laboratory of the Bureau, much valuable information relating to fire bricks made from American clays is available.

SUGGESTED DATA FOR SPECIFICATIONS BASED ON RESULTS OF LOAD TESTS FOR A STANDARD BRICK 9 INCHES LONG

| Fire Brick | Softening Temperature | Load for 1 Inch Compression—Brick Tested on End— | | Compressive Strength—Tested on End—Atmospheric Temperature—Pounds per Square Inch |
|---|---|---|---|---|
| | | Temperature | Pounds per Square Inch | |
| No. 1-A | 1690° C. | 1350° C. | 50 | 1,000 |
| No. 1-B | 1690° C. | 1350° C. | 30 | 800 |
| No. 2 | 1630° C. | 1300° C. | 25 | .... |

**Definition of Clays.**—Clays may be defined as mixtures of minerals of which the representative members are hydrous silicates of aluminum, iron, the alkalies, and the alkaline earths, of which the most characteristic is the hydrated aluminum silicate ($Al_2O_3$, $2SiO_2$, $2H_2O$). Some quartz, mica, and feldspar are usually present; the grains of these minerals may show crystal faces (especially in the case of china clays), but commonly they are of irregular shapes.

Upon most of the grains of the constituent minerals there is an enveloping coating of colloidal material, which consists of silicates, silicic acid with hydroxides of aluminium, iron, and manganese, and usually contains some organic matter.

Almost any mineral, as well as various soluble salts, may be present in clays and modify the properties somewhat. The combination of granular and colloidal material is, or should be, in such proportion that when reduced to proper size (by crushing, sifting, washing, or other means) and moistened with an appropriate amount of water plasticity is developed. If too much colloidal material is present, the clay is considered very sticky, strong, or fat; if too little, the clay is called sandy, weak, lean, or non-plastic. The term "non-plastics," for granular materials, requires qualification, since most plastic bodies would lose plasticity and become sticky if the granular constituent were removed. The highly colloidal clays are as non-plastic as the clays containing little colloidal material. In one case, the clay is too sticky to work; in the other case, it is too weak and sandy. Plasticity depends on a proper ratio between colloidal and granular matter, but within limits it varies with the amount of colloidal material present; the proportion of colloidal material in a clay is usually small and rarely exceeds 1.5 per cent; a clay containing 0.5 per cent is lean.

**Origin of Clays.**—Clays have been formed by the decomposition of feldspars, though the exact mode of formation is not yet established. That kaolinite (the crystalline mineral of the composition $Al_2O_3$, $2SiO_2$, $2H_2O$) is the chief residual product of feldspathic decay is the commonly accepted view, but some writers hold that it is not formed by ordinary weathering, and is only produced by pneumatolytic action—that is, by the operation of thermal waters and gaseous emanations. . . . . Probably different crystalline silicates yield different residues of this ill-defined class (of hydrous silicates of aluminium and iron), and any or all of them may exist in residuary clays.

Whatever be the exact process by which feldspars are transformed into clays, this much is certain, that the main agency in the removal of the alkalies and silica is water

(or dilute aqueous solutions). This removal may be effected by simple solution for, we know that in the lapse of time water dissolves the constituents of alkaline silicate out of feldspar; the process is probably furthered by mechanical factors.

**General Properties of Clays.**—Clays exhibit their characteristic properties only in presence of water; indeed, that water is present is implicit in the definition of clay, for the behavior of the dried-out clay substance differs largely from that which we ordinarily associate with clays. The principal properties of clay, besides its absorptive power, are plasticity, binding power, and shrinkage on drying or burning.

The plasticity of a clay is due to the colloidal substance which it happens to contain. When clays have been completely dried, plasticity disappears (and with it the other characteristic properties); when the material is again wetted, the plasticity is initially not so great as it was before drying out, but in the lapse of time increases slowly again. The ability of a clay to take up and to hold relatively large amounts of foreign material (such as sand, powdered minerals, etc.) without destroying its other properties is also to be attributed to the presence of colloidal material, which surrounds the foreign particles, and thus binds them together.

The shrinkage on burning is closely related to the plasticity, being greater as the plasticity is greater, for on drying there is a contraction around each individual grain due to the destruction of the colloidal material as such and the consequent formation of a multitude of cracks. It is practically impossible to dry a mass of pure clay so that it shall be free from cracks. But by suitable admixture of sand or other non-plastic material with the clay these cracks may be rendered small and separated one from another. In order to accomplish this, it is essential that the drying process be uniform throughout the mass. To insure uniformity, the drying must be conducted very slowly, and more slowly in proportion as the material used was more plastic.

The shrinkage must not be too much reduced by the addition of foreign material; otherwise the hardness will suffer. Pure clay becomes very hard on drying, while sandy pastes always remain more or less friable. This correlation does not obtain if the burning is performed at a temperature such that a partial fusion of the material may occur; but it does hold for bricks, tiles, and other refractory materials, which are burned at temperatures between 1,000° and 1,200° C.

Viscosity is an important factor in the behavior of fire brick and other clay refractories under the load conditions which prevail in industrial furnaces. While the loads imposed may be slight and would be insignificant as far as the strength of the product in the cold condition is concerned, they become an important factor at elevated temperatures. Thus, while a fire brick may show a compressive strength of from 2,500 to 3,000 pounds per square inch at atmospheric temperature, it will possess but a small part of this strength at a temperature of, say, 1,300° C.

This decrease in resistance to deformation has a more important bearing upon the durability of refractories than is generally realized. Conditions of strain prevail in almost any part of a furnace, especially in crowns, bridge walls and bags, checkerwork, retort benches, muffles, etc. To these must be added the strains imposed by expansion and contraction due to temperature changes and those due to other causes. The loss in resistance to compression is evidently due to the lowered viscosity, caused by the gradual softening of the clay due to vitrification and incipient fusion. This viscous state becomes more and more prominent as the temperature rises until the point is reached when the material can no longer support its own weight. The rate at which a clay approaches this semi-liquid state with increasing temperature may be said to be roughly proportional to the rate of vitrification, *i.e.*, the speed with which the pore space closes up due to partial fusion. The contraction is the result of surface forces tending to reduce the area of the body to a minimum.

A fire-clay body low in fluxes, *i.e.*, titanium oxide, ferric or ferrous oxide, lime, magnesia, potash and soda, showing a low rate of vitrification will consequently be affected less under furnace conditions with increasing temperatures than one higher in basic constituents.

**Nature of Refractory Clays.**—CHEMICAL COMPOSITION.—The principal ingredient of fire clay is a hydrous silicate of alumina, of the formula $Al_2O_3 . 2SiO_2 . 2H_2O$, corresponding to the following percentage composition:

| | Hydrous | Dehydrated |
|---|---|---|
| | *Per Cent* | *Per Cent* |
| Silica | 46.3 | 53.8 |
| Alumina | 39.8 | 46.2 |
| Combined water | 13.9 | .... |

While this substance, commonly called kaolin, does not correspond to the most refractory mineral combination of silica and alumina found in nature, it is at least the most commonly distributed material, since it may be assumed to be the fundamental constituent of all fire clays. Other minerals, such as sillimanite, cyanite, and andalusite, corresponding to the general formula $Al_2O_3.SiO_2$, are far more infusible, but are of comparatively rare occurrence in clays.

The so-called melting point of pure clays is close to that of platinum; that is, about 1,755° C. Substances whose softening temperatures differ too greatly from that of kaolin should not be considered as fire clays. Though the chemical composition of fire clays approaches more or less closely that of kaolinite, $Al_2O_3.2SiO_2.2H_2O$, they differ widely as regards their physical structure, varying through all stages from the well-defined crystalline state to that of a typical colloid. The fusion of even the purest clay, both in the crystalline and the amorphous condition, proceeds gradually, and it is erroneous to speak of a definite melting point for clay. In technical work the deformation and collapse of a specimen is usually employed as the criterion of the fusion point. Although this has no theoretical meaning, it answers the purposes of practice. From the technical standpoint, roughly, three classes of refractory clays may be distinguished, viz., kaolin clays, flint clays, and plastic clays.

Kaolins.—The first class of materials, usually of geologically primary origin, consists, in the purified state of white clayey matter, containing both the crystalline and amorphous varieties of clay base. In some of these clays the crystalline constituents predominate, as in the North Carolina kaolins. These clays, on account of their whiteness, are used in the pottery industries.

There are, however, kaolins which possess a good degree of plasticity, as the Georgia kaolins and some of the English china clays. These, as long as they maintain good whiteness, are highly valued in the manufacture of white ware and porcelain products. Frequently, however, increased plasticity is coincident with increased content of fluxes and consequent reduction in refractoriness. While marked plasticity in itself, of course, does not mean reduced refractoriness, it indicates geological conditions which tend to incorporate impurities in the clay.

Owing to their purity (absence of basic oxides) the kaolins are the most refractory clays.

Flint Clays.—The so-called flint clays embrace many materials of a grade of purity corresponding closely in composition to the best grade of kaolins. Like the latter, they may, of course, deteriorate into clays of comparatively low refractory value. Physically they are unlike the soft and chalky kaolins in possessing a hard, dense amorphous structure, showing a peculiar well-defined conchoidal fracture. The color is usually gray. The initial plasticity is exceedingly feeble, though if exposed to the weather or if ground either dry or wet the condition of colloidal "set" may be partially overcome and sufficient plasticity developed for molding purposes. Owing to the weak plasticity possessed by flint clays, their drying shrinkage when ground and made up with water is very slight. On the other hand, in burning these clays undergo a considerable shrinkage. The volume shrinkage characteristic of these clays subjects the structure of the product into which they enter to a severe strain, which, owing to the low tensile strength, may cause serious difficulty due to cracking and checking, so that it may be necessary either to calcine the flint clay before incorporating it in the body or to replace it in part by ground waste bricks (grog).

The burning shrinkage in the case of flint clays cannot be entirely attributed to the contraction accompanying vitrification. Considering the purity of these clays it is

evident that part of the shrinkage is independent of this factor and must be due to a molecular change of another kind, that peculiar to many typical amorphous substances like alumina, magnesia, zirconia, etc. We may, therefore, ascribe the high-burning shrinkage of flint clays to colloidal volume changes.

HIGH-GRADE PLASTIC CLAYS.—Clays, combining good plasticity and refractoriness, are not of common occurrence. While there are some examples of this type, the majority of the deposits usually show plasticity at the expense of heat-resisting power, and in addition show variations in quality which render their use in the industries more or less uncertain. Some plastic clays of high grade are known as kaolins, such as the white clays from Georgia, Alabama, and Florida. Outside of these the bulk of the plastic fire clays are of carboniferous and tertiary origin. While the kaolin-like clays are not at present used to any extent in the refractory industries they could be made available as bond clays most successfully. Owing to the higher content of impurities, the plastic clays necessarily show distinct evidence of vitrification at considerably lower temperatures than the pure fire clays.

Pure clays, up to temperatures approaching the softening point, should show no marked tendency to become dense, *i.e.*, the porosity should remain high. The lower the temperature at which the porosity of the clay becomes practically nil, the more inferior is its refractory quality. The ideal fire-clay would thus be represented by a straight line along its initial porosity, beyond a temperature of about 1,000° C., from which line impure materials depart, according to their content of fluxes.

**Manufacture of Refractories.**—The simplest case of fire-brick manufacture is that in which a highly refractory clay of sufficient plasticity can be molded into the desired shape, dried, and burnt. Since, however, this is not possible when the material is either lacking in refractory or working quality, a condition which is the rule rather than the exception, mixtures of different clays must be employed. One of the most common cases is the use of flint clay with plastic clay as the cementing agent, which produces the required working condition. A very common proportion is that of 85 per cent of flint and 15 per cent of bond clay. Such a mixture possesses sufficient plasticity to be worked by the so-called slop-mold process, but could not be molded by means of the auger machine. There is, of course, no difficulty in pressing the bricks by the dry-press process.

## EFFECT OF THE ACCESSORY CONSTITUENTS OF FIRE CLAYS UPON THE SOFTENING TEMPERATURES

Owing to the fact that clays may contain natural admixtures of various minerals and rock débris, it is necessary to consider the effect of such minerals as quartz, $SiO_2$; alumina, rutile, $TiO_2$; ferric oxide and other iron compounds, orthoclase, $K_2O$, $Al_2O_3$, $6SiO_2$; muscovite, $H_2KAl_3(SiO_4)_3$; calcite, $CaCO_3$; magnesite, $MgCO_3$; and other substances. Finally an attempt must be made to estimate the joint fluxing effect of at least the basic oxides with sufficient accuracy for technical purposes.

**Quartz.**—It was realized early in the study of fire clays that any addition of free silica to pure clay substance lowered the softening temperature. Siliceous clays hence possess an inferior ultimate refractoriness, *per se*, a fact which must be recognized in the selection of refractories. The addition of quartz also brings about a more or less pronounced increase in volume, which may show itself either by neutralizing the fire shrinkage of the clay portion or by an actual expansion. This is a fact well known in the industry. The so-called silica brick invariably expands upon being fired in the kiln, and usually still further when in actual use.

**Alumina.**—As a general proposition, it may be said that this compound improves the refractoriness of fire clays markedly. Bischof, in his well-known researches upon European fire clays, recognized this fact in his so-called refractory quotient, a value intended to indicate the relative heat-resisting property of these clays expressed by the relation $a^2 \div b$, where a = molecular equivalents of alumina to one molecular equivalent of total fluxes, RO, and b equals the corresponding molecular ratio between the silica and the fluxes. According to this, the refractoriness of a clay is proportional to the square of the alumina content. Richters also recognized the value of alumina

in this connection. In his experiments, additions of alumina raised the softening temperature of kaolin. Upon continuing the increase in alumina, the fusion temperature of sillimanite, 1,810° C., is reached, and, finally, the melting point of alumina, approximately 2,000° C.

The viscosity of silicate fusions is increased most decidedly by additions of alumina. From the practical standpoint, the addition of alumina, in the form of bauxite, to fireclay has been practised for some years with satisfactory results as far as refractoriness is concerned, but the continued contraction of the bauxite upon reheating makes it a difficult material to work. For high temperature work, fused alumina (purified bauxite) is now being introduced where the conditions warrant its use.

**Titanium Oxide.**—This compound, which may be present as rutile, $TiO_2$, ilmenite, $FeTiO_3$, or in other forms, tends to lower the softening temperature of clays distinctly.

**Iron Oxide.**—This substance in the finely divided condition is one of the most potent fluxes, and hence its presence in fire clays is very injurious as regards their behavior when subjected to higher temperatures. When present, in the form of coarser particles, occurring as siderite or pyrite, its effect is not so marked, since evidently the action is proportional to the surface factor, *i.e.*, the fineness. At the high temperatures to which refractories are exposed, the ferric oxide of the clay dissociates to one of its lower forms. According to Le Chatelier, this dissociation takes place at 1,300°; according to White and Taylor, at 1,200°, and to P. T. Walden, at 1,350° C. The last-named value represents probably the most reliable result. At this temperature, the dissociation pressure reaches 160 millimeters, which is equal to the oxygen pressure of the air. Ferric oxide hence cannot exist above this temperature. The reduction very likely results in FeO, which at the temperatures involved would at once combine with silica to form ferrous silicate, and, owing to the low fusion temperature of ferrous silicate, the resulting slag is very corrosive and attacks the clay vigorously. From the work of Cramer, it appears that iron oxide is an active flux with clays of the formula $Al_2O_3 2.5SiO_2$, while it is less active in fire clays approaching more closely the kaolin formula. Ferrous silicate, $FeSiO_3$, has been estimated to fuse at 1,110° C. in a reducing atmosphere; this value is probably too low. The viscosity of the ferrous silicates is quite low, while ferric oxide acts in the opposite direction and increases the viscosity of silicate fusions. The softening temperatures given by Hofman for various ferrous silicates are as follows:

| | |
|---|---|
| $4FeO.SiO$ | 1,280° C. |
| $3FeO.SiO_2$ | 1,220° C. |
| $2FeO.SiO_2$ | 1,270° C. |
| $3FeO.2SiO_2$ | 1,140° C. |
| $4FeO.3SiO_2$ | 1,120° C. |

**Alkalies (Feldspar).**—The alkalies present in clays occur predominatingly in the form of feldspar, orthoclase, or albite, although materials of the plastic type may contain absorbed salts in noticeable amounts. Orthoclase, $K_2O.Al_2O_3.6SiO_2$, in which some of the potash may be replaced by soda, is probably the most common feldspar. The potash feldspar is less fusible than the albite, but neither has a definite melting point. Doelter approximates that of orthoclase to be 1,190°, and the one for albite at 1,120° C.

The feldspars are so-called neutral fluxes, inasmuch as apparently they do not react chemically with the constituents of clay, like lime or magnesia. They seem to play the rôle of a solvent, and reduce the refractoriness of a fire clay in a decided manner. Zoellner states that at about 1,400° C feldspar may dissolve as much as 3.5 per cent of alumina, 14 per cent of clay substance, and 60–70 per cent of fine-grained quartz. The eutectic mixture of orthoclase and quartz consists practically of 75 per cent feldspar and 25 per cent silica. Owing to the decided viscosity of feldspar mixtures their softening point is very uncertain and has no direct connection with the effect upon vitrification.

The presence of feldspar in fire clays, while depressing the softening point, is not as detrimental to the refractory quality of the material as might appear at first. Its influence, however, upon the load-carrying ability is far more marked, since the solution effect is great enough to reduce the viscosity sufficiently to prevent the body from carrying heavier loads, though not enough to cause deformation under its own weight.

**Mica.**—This mineral, represented principally by muscovite, $H_2KAl_3(SiO_4)_3$, while depressing the softening point of a pure clay, behaves as a less effective flux than orthoclase, due both to its composition and to its physical structure.

**Lime.**—The potency of lime, as a fluxing agent in acid silicates, is well known. Cramer found that additions of calcium carbonate, from 0 to 10 per cent, to Zettlitz kaolin lowered the softening temperatures of the resulting mixtures steadily, practically in proportion to the increase in the lime content.

Rieke found that the observation of Cramer, mentioned above, held in that additions of lime to kaolin decrease the softening temperature according to a linear relation up to a mixture containing 11 per cent CaO in the calcined condition, corresponding to the formula $CaO.2Al_2O_3.4SiO_2$. Beyond this point, lime no longer reacts in a continuous manner, but shows maxima and minima, indicating the existence of at least two compounds.

The viscosity of the calcium silicates of the more acid type is quite low, as is shown by practical experience in the working of calcareous clays. It is a well-known fact that such materials deform and flow when heated in the kiln beyond the vitrification temperature more readily than other clays.

**Joint Effect of Fluxes Upon the Refractoriness.**—RICHTERS' LAW.—Many attempts have been made to correlate the effect of the basic fluxes upon the softening temperature of fire clays. Thus Richters, in 1868, enunciated the rule that molecularly equivalent amounts of the bases exert the same effect in depressing the softening temperature of fire clays. According to this rule, 40 parts, by weight, of magnesia would lower the refractoriness to the same extent as 56 parts of lime or 94 of potash. This statement is supposed to apply only to small amounts of these substances added to the purer type of clays.

**Bischof's Refractory Quotient.**—Bischof proposed a so-called refractory quotient calculated from the formula obtained from the chemical analysis. Letting the molecular equivalents of $Al_2O_3$ = a, those of the $SiO_2$ = b, and of the fluxing oxide = c, and expressing the ratio a ÷ c by A, and the ratio b ÷ a by B, the refractory quotient is represented by the expression.

$$\frac{A}{B} = \frac{a \div c}{b \div a} = \frac{a^2}{bc}.$$

According to this, the refractoriness would be proportional to the square of the alumina and inversely proportional to the silica and flux contents.

**Vitrification.**—Vitrification as related to refractory behavior of clays. It is agreed by workers in this field that the fluxes bring about a large part of the contraction suffered by clays upon being heated to elevated temperatures. While the action due to this cause, as measured by the contraction in volume, is but slight at lower temperatures, it is accelerated as the temperature rises. This is due to the fact that solution is in progress. Starting from the initial temperature of activity, such a selective solution of the fluxes, alumina and silica, tends to take place which softens at this point. With the rise in temperature, the composition of this softened portion changes by the incorporation and solution of more of the clay body, and evidently the mass of the softened portion increases correspondingly. Thus with every advance in temperature the softened portion constitutes a larger percentage of the whole, until finally it possesses the composition of the body, *i.e.*, when all of it softens and the so-called melting point has been reached.

**Decrease in Density During Vitrification.**—It is interesting to note that during the solution process going on throughout vitrification the density of the clay mass itself decreases proportionally to the contraction in pore space. The more fluxes a clay contains—*i.e.*, the more deficient in refractoriness it is—the lower must be the temperature at which all pore space has been filled by the softened matter; in other words, the lower its temperature of vitrification.

## LOAD TESTS OF FIRE BRICK

In the course of the experiments more than 35 brands of fire brick were tested, as well as specimens made in the clay-products laboratory from different fire clays. Samples

were obtained from manufacturers located in Pennsylvania, Maryland, Ohio, New Jersey, Missouri, Kentucky, and Colorado. For obvious reasons, the names of the brands cannot be given. The number of each material remains the same for all of the different tests.

**Load Test.**—In carrying out the load test, the beam is first raised as the temperature rises, due to the expansion of the furnace bottom and the brick; a quiescent stage is then reached, after which, from 1,130° to 1,290° C., a well-defined deflection begins, caused by the contraction of the brick. In some bricks, this deflection continues at a very slow rate or reaches a state of equilibrium some time after the temperature has been raised to 1,300° C. This kind does not fail under the conditions of the test, and the later deflection starts the more apt is the brick to stand up. The materials failing under the test show a more or less early start in settling, and the rate at which this takes place increases with the temperature, till finally it becomes so rapid that it is impossible to keep the beam level. Failure then is merely a matter of minutes and takes place very suddenly. In every case, softening precedes failure.

**Accessory Tests.**—In addition to the load tests, the following determinations were made: 1, chemical analysis; 2, crushing strength of the bricks on end in the cold condition; 3, softening temperature; 4, porosity; 5, true density. Twenty bricks of each brand were secured and check determinations made.

**Results of the Load Test Series, 75 Pounds per Square Inch at 1,300° C.**—The results of the physical tests of this series are arranged in Table III. The typical failures show that where the bricks were badly distorted and crushed in each case a certain degree of softening took place, as was clearly indicated by their curved surfaces. It is evident that these bricks attained a viscous condition, in which they were not able to carry the load imposed upon them, though the latter is small as compared with the crushing strength at the atmospheric temperature, which for the 26 samples tested averaged 1,520 pounds per square inch. Inspection of the failures showed plainly that the more refractory flint clay had not softened to the slightest extent. The grains had lost none of their original identity. They seemed to have slid upon each other, the bond clay behaving analogously to a lubricant. From this it follows that no matter how excellent the major constituent of the brick may be as to refractoriness, if the bond clay is too deficient in this respect the load-carrying power of the product is impaired.

**Effect of Chemical Composition.**—Assuming that the fire brick body consists of a refractory constituent corresponding in composition to the kaolin formula and of a more fusible cementing component, the following method might be pursued to show theoretically the make-up of the mixture. Taking, for example, one of the failures, say sample No. 4, and calculating the empirical formula, the latter is found to be: 0.019 $Na_2O$, 0.030 $K_2O$, 0.036 $MgO$, 0.026 $CaO$, 0.14 $FeO$, 0.054 $TiO_2$, 1.00 $Al_2O_3$, 2.485 $SiO_2$. Upon the assumption that the alkalies are derived from orthoclase feldspar, the molecular equivalents of the latter would be $0.019 + 0.030 = 0.049$. Deducting the alumina belonging to the feldspar from 1, we obtain 0.951 equivalent $Al_2O_3$ present as clay substance, which corresponds to 1.902 equivalent of $SiO_2$. Subtracting this from 2.485 leaves 0.583 equivalent silica. Multiplying the equivalents by the respective molecular weights and reducing to the percentage basis we find the following distribution of clay substance, feldspar and free silica:

| | Per Cent |
|---|---|
| Clay substance | 77.23 |
| Feldspar | 10.06 |
| Fluxes and free silica | 12.71 |

This shows an excessive amount of fluxing material in proportion to the clay base, but the case is still more striking, since the composition of the fluxes and the free silica upon calculation reduces to the formula (using $RO = 1$, as is customary for slags and glasses): $RO\ 1.43\ SiO_2 . 0.267\ TiO_2$. This represents a slag which is not saturated with silica at the temperatures involved, and hence it is certain to attack the clay substance, thus bringing into solution still more material and increasing the proportion of fusible to refractory constituents.

## TABLE 1

### Fire Brick and Clay Analyses

| No. | $SiO_2$ | $Al_2O_3$ | $FeO_3$ | $TiO_2$ | CaO | MgO | $Na_2O$ | $K_2O$ | $SO_3$ | $H_2O$ at 100°C | Ignition Loss | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 81.60 | 14.55 | 1.15 | 0.49 | 0.37 | 0.27 | 0.67 | 1.08 | | | | 100.18 |
| 2 | 79.20 | 17.42 | 1.19 | .49 | .21 | .38 | .37 | .91 | | | | 100.17 |
| 3 | 77.02 | 18.35 | 1.32 | .52 | .48 | .28 | .67 | 1.49 | | | | 100.13 |
| 4 | 54.58 | 37.35 | 4.10 | 1.57 | .54 | .53 | .42 | 1.02 | | | | 100.11 |
| 5 | 54.70 | 39.72 | 1.32 | 1.86 | .29 | .52 | .64 | 1.07 | | | | 100.12 |
| 6 | 54.69 | 38.86 | 1.41 | 1.92 | .35 | .52 | .91 | 1.57 | | | | 100.23 |
| 7 | 54.25 | 38.90 | 1.83 | 1.92 | .41 | .78 | .78 | 1.26 | | | | 100.13 |
| 8 | 52.30 | 41.52 | 1.28 | 2.46 | 1.02 | .45 | .28 | .94 | | | | 100.25 |
| 9 | 63.89 | 29.28 | 2.05 | 2.40 | .27 | .29 | .40 | 1.71 | | | | 100.29 |
| 10 | 60.37 | 34.83 | 1.37 | 2.05 | .39 | .31 | .20 | .67 | | | | 100.19 |
| 11 | 61.35 | 32.65 | 2.15 | 1.98 | .46 | .50 | .17 | .86 | | | | 100.12 |
| 12 | 55.66 | 36.52 | 2.59 | 2.40 | .49 | .61 | .18 | 1.73 | | | | 100.18 |
| 13 | 68.73 | 25.12 | 2.26 | 1.32 | .36 | .49 | .25 | 1.62 | | | | 100.15 |
| 14 | 60.77 | 32.63 | 2.89 | 1.94 | 1.12 | .26 | .26 | .46 | | | | 100.33 |
| 15 | 56.55 | 36.64 | 2.84 | 1.90 | 1.34 | .22 | .32 | .43 | | | | 100.25 |
| 16 | 50.76 | 44.24 | 1.45 | 2.03 | .33 | .29 | .34 | .60 | | | | 100.04 |
| 17 | 62.14 | 32.29 | 2.65 | 1.42 | .71 | .50 | .13 | .38 | | | | 100.22 |
| 18 | 62.74 | 31.80 | 2.45 | 1.53 | .75 | .56 | .18 | .18 | | | | 100.19 |
| 19 | 35.46 | 57.98 | 1.40 | 2.70 | .29 | .29 | .75 | 1.30 | | | | 100.17 |
| 20 | 52.89 | 43.41 | .90 | 2.12 | .16 | .13 | .36 | .27 | | | | 100.24 |
| 21 | 65.41 | 29.50 | 2.75 | 1.38 | .45 | .25 | .10 | .34 | | | | 100.18 |
| 22 | 66.53 | 28.66 | 2.35 | 1.36 | .58 | .42 | .28 | .19 | | | | 100.37 |
| 23 | 66.28 | 29.12 | 1.55 | 1.79 | .59 | .23 | .27 | .30 | | | | 100.13 |
| 24 | 77.82 | 19.00 | 1.01 | 1.65 | .22 | .06 | .10 | .28 | | | | 100.14 |
| 25 | 56.62 | 39.19 | 1.95 | 1.69 | .36 | .08 | .18 | .19 | | | | 100.26 |
| 26 | 54.51 | 40.42 | 1.90 | 2.46 | .35 | .17 | .16 | .20 | | | | 100.17 |
| 27 | 65.59 | 28.95 | 1.45 | .93 | .35 | .60 | .63 | 1.21 | | | 0.45 | 100.16 |
| 28 | 62.81 | 31.85 | 1.27 | 1.33 | .28 | tr | .53 | 1.72 | tr | 0.05 | .30 | 100.14 |
| 29 | 68.15 | 26.30 | 1.97 | 1.10 | .11 | .23 | .56 | 1.53 | | | .25 | 100.20 |
| 30 | 65.34 | 30.01 | 1.45 | .88 | .18 | .52 | .38 | 1.21 | | | .28 | 100.25 |
| 31 | 72.74 | 17.77 | .80 | 1.55 | .13 | tr | .13 | .27 | | .18 | 6.55 | 100.12 |
| 32 | 56.69 | 29.48 | 1.20 | 1.87 | .25 | .12 | .36 | 1.21 | tr | .82 | 8.20 | 100.20 |
| 33 | 53.27 | 31.72 | 1.16 | 1.93 | .21 | .08 | .30 | .97 | tr | .83 | 9.72 | 100.19 |
| 34 | 66.05 | 25.45 | 1.06 | 1.40 | .20 | .37 | .30 | 1.05 | tr | .23 | 4.05 | 100.16 |
| 35 | 58.88 | 26.41 | 1.35 | 1.22 | .35 | .42 | .34 | 1.64 | .01 | .72 | 8.85 | 100.19 |
| 36 | 64.70 | 21.90 | 1.47 | .86 | .45 | .60 | .42 | 2.16 | .02 | .65 | 6.96 | 100.19 |
| | | | FeO | | | | | | | | | |
| 37 | 85.00 | 10.55 | 2.85 | .42 | .40 | .43 | .16 | | | | | 99.81 |
| 38 | 85.30 | 11.95 | 1.85 | .30 | .20 | .29 | .24 | | | | | 100.13 |
| [60] 39 | 52.64 | 41.12 | 1.28 | .74 | 1.23 | .77 | .55 | .78 | | | 1.15 | 100.26 |

[60] A German fire brick of good quality.

TABLE 2

CHEMICAL FORMULAS

| No. | $Al_2O_3$ | $SiO_2$ | $TiO_2$ | FeO | CaO | MgO | $Na_2O$ | $K_2O$ | Total RO |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.0 | 9.180 | 0.041 | 0.098 | 0.045 | 0.046 | 0.074 | 0.079 | 0.342 |
| 2 | 1.0 | 7.732 | .036 | .087 | .022 | .056 | .035 | .057 | .257 |
| 3 | 1.0 | 7.140 | .036 | .092 | .037 | .038 | .060 | .088 | .315 |
| 4 | 1.0 | 2.485 | .054 | .140 | .026 | .036 | .019 | .030 | .251 |
| 5 | 1.0 | 2.343 | .057 | .042 | .013 | .033 | .038 | .043 | .169 |
| 6 | 1.0 | 2.386 | .064 | .046 | .016 | .034 | .038 | .044 | .178 |
| 7 | 1.0 | 2.365 | .064 | .060 | .019 | .051 | .033 | .035 | .198 |
| 8 | 1.0 | 2.142 | .075 | .039 | .045 | .028 | .011 | .025 | .148 |
| 9 | 1.0 | 3.710 | .105 | .089 | .017 | .025 | .022 | .063 | .216 |
| 10 | 1.0 | 2.947 | .075 | .050 | .020 | .023 | .009 | .021 | .123 |
| 11 | 1.0 | 3.196 | .077 | .064 | .026 | .039 | .009 | .029 | .167 |
| 12 | 1.0 | 2.591 | .085 | .090 | .024 | .043 | .008 | .051 | .216 |
| 13 | 1.0 | 4.651 | .067 | .115 | .026 | .050 | .002 | .070 | .263 |
| 14 | 1.0 | 3.168 | .076 | .113 | .063 | .020 | .013 | .015 | .224 |
| 15 | 1.0 | 2.634 | .066 | .099 | .067 | .015 | .014 | .013 | .208 |
| 16 | 1.0 | 1.952 | .059 | .042 | .014 | .017 | .013 | .015 | .101 |
| 17 | 1.0 | 3.294 | .051 | .104 | .040 | .039 | .007 | .013 | .203 |
| 18 | 1.0 | 3.354 | .061 | .100 | .043 | .037 | .009 | .006 | .195 |
| 19 | 1.0 | 1.040 | .059 | .031 | .009 | .013 | .021 | .014 | .088 |
| 20 | 1.0 | 2.072 | .062 | .003 | .004 | .076 | .016 | .007 | .106 |
| 21 | 1.0 | 3.770 | .060 | .119 | .003 | .022 | .006 | .013 | .163 |
| 22 | 1.0 | 3.930 | .060 | .104 | .037 | .037 | .016 | .007 | .201 |
| 23 | 1.0 | 3.871 | .078 | .069 | .037 | .020 | .015 | .011 | .152 |
| 24 | 1.0 | 6.953 | .111 | .068 | .021 | .008 | .009 | .016 | .122 |
| 25 | 1.0 | 2.458 | .055 | .063 | .019 | .005 | .008 | .005 | .100 |
| 26 | 1.0 | 2.293 | .078 | .060 | .016 | .011 | .007 | .005 | .099 |
| 27 | 1.0 | 3.850 | .041 | .064 | .022 | .052 | .036 | .045 | .219 |
| 28 | 1.0 | 3.251 | .052 | .049 | .015 | tr | .027 | .057 | .148 |
| 29 | 1.0 | 4.410 | .053 | .095 | .008 | .022 | .035 | .063 | .223 |
| 30 | 1.0 | 3.693 | .037 | .061 | .011 | .044 | .021 | .044 | .181 |
| 31 | 1.0 | 7.000 | .112 | .058 | .013 | tr | .012 | .017 | .100 |
| 32 | 1.0 | 3.270 | .081 | .052 | .015 | 010 | .020 | .045 | .142 |
| 33 | 1.0 | 2.854 | .077 | .047 | .012 | .006 | .016 | .033 | .114 |
| 34 | 1.0 | 4.413 | .070 | .052 | .014 | .037 | .019 | .045 | .167 |
| 35 | 1.0 | 3.789 | .059 | .065 | .024 | .040 | .021 | .067 | .217 |
| 36 | 1.0 | 4.320 | .043 | .074 | .037 | .060 | .032 | .107 | .310 |
| 37 | 1.0 | 13.680 | .051 | .377 | .069 | .103 | .025 | .... | .574 |
| 38 | 1.0 | 12.130 | .032 | .216 | .030 | .061 | .033 | .... | .340 |
| 39 | 1.0 | 2.18 | .022 | .040 | .055 | .047 | .022 | .020 | .184 |

## TABLE 3

RESULTS OF PHYSICAL TESTS AT 1,300° C AND WITH A LOAD OF 75 POUNDS PER SQUARE INCH

| No. | Dimensions, in Inches, Before | Dimensions, in Inches, After | Linear Compression, in Inches | Deformation Started | Cold Crush-Strength | Per Cent Porosity | Softening Point in Cones | Specific Gravity |
|---|---|---|---|---|---|---|---|---|
| | | | | °C | | | | |
| 1 | 9 by $4\frac{3}{8}$ by $2\frac{1}{2}$ | Crushed | ... | 1213 | 1464 | 30.2 | 28 | 2.671 |
| 2 | 9 by $4\frac{3}{8}$ by $2\frac{1}{2}$ | Crushed | ... | 1247 | 1289 | 30.1 | 28 | 2.638 |
| 3 | $8\frac{7}{8}$ by $4\frac{1}{4}$ by $2\frac{1}{2}$ | Crushed | ... | 1210 | 989 | 32.4 | 28 | 2.635 |
| 4 | 9 by $4\frac{1}{2}$ by $2\frac{1}{2}$ | Crushed | ... | 1180 | 495 | 25.8 | 29 | 2.755 |
| 5 | $8\frac{7}{8}$ by $4\frac{1}{4}$ by $2\frac{3}{8}$ | $8\frac{1}{8}$ by $4\frac{1}{2}$ by $2\frac{9}{16}$ | $\frac{3}{4}$ | 1191 | 1160 | 23.0 | $31\frac{1}{2}$ | 2.732 |
| 6 | 9 by $4\frac{1}{2}$ by $2\frac{3}{8}$ | $8\frac{1}{4}$ by $4\frac{1}{16}$ by $2\frac{7}{16}$ | $\frac{3}{4}$ | 1213 | 931 | 22.9 | 31 | 2.691 |
| 7 | 9 by $4\frac{1}{2}$ by $2\frac{1}{2}$ | $7\frac{3}{4}$ by $4\frac{9}{16}$ by $2\frac{5}{8}$ | $1\frac{1}{4}$ | 1215 | 674 | 20.7 | 31 | 2.717 |
| 8 | $8\frac{3}{4}$ by $4\frac{1}{4}$ by $2\frac{1}{2}$ | $8\frac{3}{8}$ by $4\frac{1}{4}$ by $2\frac{5}{8}$ | $\frac{3}{8}$ | 1295 | 1082 | 17.1 | 34 | 2.712 |
| 9 | $8\frac{7}{8}$ by $4\frac{3}{8}$ by $2\frac{3}{8}$ | Crushed | ... | 1191 | 612 | 29.4 | $29\frac{1}{2}$ | 2.674 |
| 10 | $8\frac{7}{8}$ by $4\frac{1}{4}$ by $2\frac{1}{2}$ | $8\frac{1}{2}$ by $4\frac{5}{16}$ by $2\frac{1}{2}$ | $\frac{3}{8}$ | 1179 | 946 | 27.5 | 33 | 2.702 |
| 11 | 9 by $4\frac{1}{4}$ by $2\frac{1}{2}$ | $7\frac{1}{2}$ by $4\frac{5}{8}$ by $2\frac{1}{2}$ | $1\frac{1}{2}$ | 1133 | 480 | 25.1 | 28 | 2.678 |
| 12 | 9 by $4\frac{3}{8}$ by $2\frac{1}{2}$ | Crushed | ... | 1142 | 2614 | 24.5 | $24\frac{1}{2}$ | 2.724 |
| 13 | $8\frac{3}{4}$ by $4\frac{1}{2}$ by $2\frac{1}{2}$ | Crushed | ... | 1130 | 843 | 22.5 | $28\frac{1}{2}$ | 2.664 |
| 14 | $8\frac{7}{8}$ by $4\frac{1}{8}$ by $2\frac{1}{2}$ | $8\frac{5}{16}$ by $4\frac{1}{4}$ by $2\frac{7}{16}$ | $\frac{9}{16}$ | 1211 | 2226 | 25.5 | $31\frac{1}{2}$ | 2.725 |
| 15 | $8\frac{7}{8}$ by $4\frac{1}{4}$ by $2\frac{1}{4}$ | $7\frac{7}{8}$ by $4\frac{3}{8}$ by $2\frac{7}{16}$ | 1 | 1234 | 1638 | 23.1 | 31 | 2.705 |
| 16 | 9 by $4\frac{3}{8}$ by $2\frac{1}{2}$ | 8 by $4\frac{1}{2}$ by $2\frac{9}{16}$ | 1 | 1205 | 971 | 24.3 | 34 | 2.712 |
| 17 | $8\frac{3}{4}$ by $4\frac{1}{4}$ by $2\frac{3}{8}$ | $8\frac{1}{16}$ by $4\frac{3}{8}$ by $2\frac{1}{2}$ | $\frac{13}{16}$ | 1233 | 2578 | 23.9 | 31— | 2.712 |
| 18 | $8\frac{7}{8}$ by $4\frac{1}{4}$ by $2\frac{1}{2}$ | $8\frac{3}{16}$ by $4\frac{9}{16}$ by $2\frac{1}{2}$ | $\frac{13}{16}$ | 1274 | 955 | 21.0 | 32 | 2.647 |
| 19 | $9\frac{1}{8}$ by $4\frac{1}{2}$ by $2\frac{1}{2}$ | $8\frac{1}{2}$ by $4\frac{9}{16}$ by $2\frac{1}{2}$ | $\frac{5}{8}$ | 1235 | 2071 | 33.3 | 33+ | 2.975 |
| 20 | $8\frac{3}{4}$ by $4\frac{1}{4}$ by $2\frac{1}{2}$ | $8\frac{1}{2}$ by $4\frac{7}{16}$ by $2\frac{1}{2}$ | $\frac{1}{4}$ | 1213 | 2005 | 26.8 | 31 | 2.738 |
| 21 | $8\frac{7}{8}$ by $4\frac{1}{4}$ by $2\frac{1}{2}$ | $8\frac{9}{16}$ by $4\frac{3}{8}$ by $2\frac{7}{16}$ | $\frac{5}{16}$ | 1231 | 3174 | 22.2 | 31 | 2.668 |
| 22 | $8\frac{7}{8}$ by $4\frac{1}{4}$ by $2\frac{1}{2}$ | $8\frac{1}{4}$ by $4\frac{3}{8}$ by $2\frac{9}{16}$ | $\frac{5}{8}$ | 1234 | 2191 | 26.8 | 31 | 2.676 |
| 23 | $8\frac{7}{8}$ by $4\frac{3}{8}$ by $2\frac{1}{2}$ | $8\frac{5}{16}$ by $4\frac{5}{16}$ by $2\frac{1}{2}$ | $\frac{9}{16}$ | 1264 | 4234 | 23.9 | 31 | 2.677 |
| 24 | 9 by $4\frac{3}{8}$ by $2\frac{1}{2}$ | $8\frac{7}{8}$ by $4\frac{3}{8}$ by $2\frac{1}{2}$ | $\frac{1}{8}$ | 0 | 2551 | 27.5 | 29 | 2.622 |
| 25 | 9 by $4\frac{1}{4}$ by $2\frac{3}{8}$ | $8\frac{3}{4}$ by $4\frac{1}{4}$ by $2\frac{9}{16}$ | $\frac{1}{4}$ | 1291 | 1241 | 26.3 | $31\frac{1}{2}$ | 2.702 |
| 26 | $8\frac{7}{8}$ by $4\frac{1}{4}$ by $2\frac{1}{2}$ | $7\frac{5}{8}$ by $4\frac{1}{2}$ by $2\frac{1}{2}$ | $1\frac{1}{4}$ | 1207 | 1138 | 22.3 | 31 | 2.744 |
| 27 | 8 by $3\frac{3}{4}$ by $2\frac{1}{4}$ | Crushed | ... | 1168 | 4042 | 18.1 | 26 | 2.682 |
| 28 | 9 by $4\frac{1}{2}$ by $2\frac{5}{8}$ | $8\frac{5}{8}$ by $4\frac{1}{2}$ by $2\frac{5}{8}$ | $\frac{3}{8}$ | 1215 | 2509 | 27.4 | $31\frac{1}{2}$ | 2.643 |

**Influence of the Cold-Crushing Strength.**—A comparison of the initial, cold, crushing strength and the load behavior shows no apparent connection, but the fact is brought out that low initial strength is a handicap. Bricks Nos. 4 and 11 are examples of this kind. While No. 4 would have failed irrespective of its cold-crushing strength, the failure was more complete on account of its weakness, and No. 11 in all probability would have shown a very much smaller condensation; in fact, it might have stood the test.

The hardness of burning, in general, is a factor worthy of consideration. Although firing to a high temperature cannot, in the nature of the case, effect any fundamental change, and cannot convert a low-grade material into a good one, the work of the

bureau has shown that well-burnt bricks stand up better than soft-burnt products. This is due, not only to the greater compactness of the body, but also the change in the composition of the bonding material where such is used. In other words, hard burning will cause the usually decidedly less refractory, plastic clay to dissolve some of the fine part of the better material (flint clay), thus increasing its own refractoriness, and hence its resistance to load conditions. For instance, No. 26 would have shown up better if it had been burnt harder.

## RESULTS OF THE TESTS AT 1,350° C. AND WITH A LOAD OF 50 POUNDS PER SQUARE INCH

**Comparison with Results of 1,300° Test.**—The results of this series are compiled in Table 4. Not all of the 1,300-degree load tests were repeated, but only a sufficient number to establish the relative severity of each condition. In comparing the data obtained in the two series it was found that the results were approximately the same,

### TABLE 4

Results of Physical Tests at 1,350° C and with a Load of 50 Pounds per Square Inch

| No. | Dimensions, in Inches, Before | Dimensions, in Inches, After | Linear Compression, in Inches | Deformation Started | Cold Crush-Strength | Per Cent Porosity | Softening Point in Cones | Specific Gravity |
|---|---|---|---|---|---|---|---|---|
| | | | | °C | | | | |
| 2B | 9 by $4\frac{3}{8}$ by $2\frac{3}{8}$ | Crushed | ... | 1220 | 1289 | 30.1 | 28 | 2.638 |
| 4B | $8\frac{7}{8}$ by $4\frac{3}{8}$ by $2\frac{1}{2}$ | Crushed | ... | 1175 | 495 | 25.8 | 29 | 2.755 |
| 7B | $8\frac{7}{8}$ by $4\frac{3}{8}$ by $2\frac{3}{8}$ | $8\frac{1}{8}$ by $4\frac{3}{8}$ by $2\frac{1}{2}$ | $\frac{3}{4}$ | 1218 | 674 | 20.7 | 31 | 2.717 |
| 9B | 9 by $4\frac{1}{4}$ by $2\frac{1}{2}$ | Crushed | ... | 1238 | 612 | 29.4 | $29\frac{1}{2}$ | 2.674 |
| 11B | $8\frac{7}{8}$ by $4\frac{3}{8}$ by $2\frac{3}{8}$ | Crushed | ... | 1165 | 480 | 25.1 | 28 | 2.678 |
| 12B | 9 by $4\frac{3}{8}$ by $2\frac{3}{8}$ | Crushed | ... | 1175 | 2614 | 24.5 | $24\frac{1}{2}$ | 2.724 |
| 13B | $8\frac{3}{4}$ by $4\frac{1}{4}$ by $2\frac{1}{2}$ | Crushed | ... | 1150 | 843 | 22.5 | $28\frac{1}{2}$ | 2.664 |
| 15B | $8\frac{7}{8}$ by $4\frac{1}{4}$ by $2\frac{1}{2}$ | $7\frac{3}{4}$ by $4\frac{1}{2}$ by $2\frac{1}{2}$ | $1\frac{1}{8}$ | 1245 | 1638 | 23.1 | 31 | 2.705 |
| 19B | $9\frac{1}{16}$ by $4\frac{7}{16}$ by $2\frac{1}{16}$ | $8\frac{1}{2}$ by $4\frac{1}{2}$ by $2\frac{9}{16}$ | $\frac{9}{16}$ | 1200 | 2071 | 33.3 | 33+ | 2.975 |
| 20B | $8\frac{7}{8}$ by $4\frac{1}{4}$ by $2\frac{1}{2}$ | Note: 4 hours at 1350° | $\frac{7}{8}$ | .... | 2005 | 26.8 | 31 | 2.738 |
| 23B | $8\frac{7}{8}$ by $4\frac{3}{8}$ by $2\frac{1}{2}$ | $8\frac{1}{8}$ by $4\frac{1}{2}$ by $2\frac{1}{2}$ | $\frac{3}{4}$ | 1290 | 4234 | 23.9 | 31 | 2.677 |
| 26B | 9 by $4\frac{1}{4}$ by $2\frac{1}{2}$ | 8 by $4\frac{3}{8}$ by $2\frac{1}{2}$ | 1 | 1220 | 1138 | 22.3 | 31 | 2.744 |
| 29 | 9 by $4\frac{1}{4}$ by $2\frac{1}{2}$ | Crushed | ... | 1230 | 4714 | 22.2 | 29 | 2.627 |
| 30 | $8\frac{1}{2}$ by $4\frac{1}{4}$ by $2\frac{1}{4}$ | Crushed | ... | 1180 | 1585 | 27.9 | $26\frac{1}{2}$ | 2.653 |
| 31 | $8\frac{7}{8}$ by $4\frac{3}{8}$ by $2\frac{3}{8}$ | $8\frac{5}{8}$ by $4\frac{1}{2}$ by $2\frac{3}{8}$ | $\frac{1}{4}$ | 1250 | 1054 | 30.6 | 30 | 2.654 |
| 32 | 8 by $3\frac{3}{4}$ by $2\frac{1}{8}$ | $7\frac{1}{2}$ by $3\frac{7}{8}$ by $2\frac{1}{8}$ | $\frac{1}{2}$ | 1330 | 2829 | 32.5 | 31 | 2.565 |
| 33 | $7\frac{7}{8}$ by $3\frac{3}{4}$ by 2 | $7\frac{3}{8}$ by $3\frac{3}{4}$ by 2 | $\frac{1}{2}$ | 1330 | 9008 | 12.4 | 32 | 2.655 |
| 34 | $8\frac{1}{4}$ by 4 by $2\frac{1}{4}$ | Crushed | ... | 1180 | 7819 | 7.4 | 25 | 2.521 |
| 35 | $8\frac{7}{16}$ by 4 by $2\frac{1}{8}$ | $7\frac{9}{16}$ by 4 by $2\frac{1}{8}$ | $\frac{5}{8}$ | 1280 | 7404 | 12.0 | $30\frac{1}{2}$ | 2.618 |
| 36 | $8\frac{1}{2}$ by 4 by $2\frac{1}{4}$ | Crushed | ... | 1200 | 4368 | 17.4 | $27\frac{1}{2}$ | 2.649 |
| 37 | $8\frac{3}{4}$ by $4\frac{1}{4}$ by $2\frac{1}{2}$ | Crushed | ... | 1180 | 1725 | 23.8 | 29 | 2.490 |
| 38 | 9 by $4\frac{1}{2}$ by $\left\{\begin{matrix}3\frac{3}{4}\\2\end{matrix}\right.$ | Crushed | ... | 1150 | 1910 | 23.8 | 29 | 2.575 |
| 39 | $4\frac{1}{2}$ by $2\frac{5}{16}$ by 3 | $4\frac{15}{32}$ by $2\frac{5}{16}$ by 3 | $\frac{1}{32}$ | .... | .... | .... | $33\frac{1}{2}$ | ..... |

with the exception that the 1,350-degree 50-pound tests appeared to be somewhat more sensitive and differentiated more sharply between the various kinds of refractories.

The compression effect in the second test was found to be somewhat greater than in the first test. Both tests, however, condemned inferior materials with practically equal certainty.

The pressure effect appears to be more prominent in the 1,300-degree 75-pound series, while under the second conditions the softening due to heat is more pronounced. There is more deformation in the sense of flow in the 50-pound series. In considering furnace conditions it is at once evident that everywhere pressures are to be resisted, and not only those due to loads, but also the compression and tension stresses caused by thermal expansion and contraction. The higher the furnace temperature the more rapidly is the load-carrying ability reduced until finally the refractory is unable to support its own weight.

The load test, therefore, measures the viscosity of the fire-clay bodies at a certain temperature. Since any good refractory should possess sufficient rigidity at the temperature at which it is to be used to carry the load or to resist the pressure it is called upon to meet, it is evident that a fire-brick lacking in this respect is as inferior as a material showing a low softening temperature.

## STRUCTURAL TIMBERS USED IN ENGINEERING

Timber is a general term applied to wood of suitable size and quality for structural purposes; it is practically unchangeable in the direction of its length; it is both inextensible and incompressible in that direction, being readily wrought and easily combined with other timber as a valuable structural material, but it shrinks and swells in the direction of its thickness; it is subject to rapid decay when exposed to alternations of moisture and dryness. In many varieties timber is durable and unchangeable in form if free from moisture or always wholly wet. Timber offers comparatively slight resistance to compressing power; the comparative ease with which its fibrous structure is torn asunder limits its employment in that direction, since it cannot be grasped or otherwise held in any degree proportioned to its strength; it readily absorbs moisture by the ends of the fiber, and with a more mischievous effect than in the direction in which it is compressible; hence, timber rots more rapidly by the ends than by the sides. The characteristics of some American woods used in structural work are here given, based on the records of the United States Forest Products Laboratory.

### SOUTHERN YELLOW PINES

The term Southern yellow pine is applied collectively to practically all of the pines of the Southern States which are manufactured into lumber. These pines are often roughly divided into three classes: Longleaf, shortleaf, and loblolly pines. The wood of all the Southern pines is very much alike in appearance. The sapwood and heartwood are distinctly marked, the sapwood being yellowish white and the heartwood reddish brown.

The specific gravity of the springwood is about 0.40, while that of the summerwood is about 0.95, so that the weight of the wood increases with the larger proportion of summerwood, which generally forms less than half of the total volume of the whole log.

Summerwood varies somewhat in proportion, according to age, and is generally greatest in early middle life and least in extreme youth and old age. On an average, the amount of summerwood is greater in longleaf than in shortleaf or loblolly.

The grain of the Southern pines is generally straight, but some trees have a spiral growth which causes "cross-grained" lumber; the fibers or cells running lengthwise with the trunk form about 90 per cent of the wood by volume, and the pith rays placed at right angles to them and lying radially form about 8 per cent. The remaining 2 per cent is made up of the resin ducts.

Annual rings, or layers of growth, show distinctly in the wood of these pines, and the width of the annual rings generally varies with the age period of the tree, being greatest when the tree is young and vigorous and least in the sapwood of mature trees. The

two bands of dark summerwood and lighter colored springwood in each year's growth are distinct in the Southern pines.

Sapwood contains less resinous matter than does the heartwood. The heartwood of old logs is generally heavier than the sapwood on account of being formed when the tree was comparatively young and vigorous. Of the three principal pines, longleaf has the least sapwood and loblolly the most, while shortleaf occupies an intermediate position.

Shrinkage of Southern pines, as when a piece of green or wet wood is dried, does not change its dimensions until the fiber-saturation point is passed; the wood then begins to shrink in cross-sectional area until no further moisture can be extracted from the cell walls, the contraction varying uniformly with the removal of moisture. Generally, the heaviest wood shrinks the most, and sapwood shrinks about 25 per cent more than heartwood of the same specific gravity.

The use of Southern pines is not confined to building operations, but furnishes some twenty million railroad ties annually; a considerable portion of these ties is treated with either creosote oil or zinc chloride. The average life of the untreated sap tie is about three years, while that of a properly treated sap tie is about fifteen years. Loblolly and shortleaf are used to a large extent in mining operations as both round and sawed timber; the conditions in mines are such as to cause timber to decay very rapidly.

**Longleaf Pine** (*Pinus palustris*) has long been a standard construction timber, not only on account of its strength, hardness, and durability, but also on account of the good lengths of heartwood that can be obtained free from knots.

Characteristics: Longleaf pine has a fine and even grain; annual rings uniformly narrow, generally 12 to 20 rings per inch. Color is generally even; dark-reddish yellow to reddish brown. Sapwood rarely over 2 to 3 inches of radius in trees 12 inches diameter. Resin very abundant, pitchy throughout.

In the markets at present any heart pine, whether longleaf, shortleaf, or loblolly, which shows a close-ringed, hard texture, is sold under the name of longleaf pine, while the wider ringed, more rapid and sappy growth is sold as shortleaf pine. The names "Georgia pine" and "Alabama pine" are often used to designate timber coming from the tracts of longleaf pine in those States.

Specific gravity of kiln-dried longleaf pine has a possible range of 0.50 to 0.90; the most frequent range is 0.55 to 0.65; averaging about 37.5 pounds per cubic foot.

In weight, the average per cubic foot of dry Georgia pine is 42.9 pounds as against 36.2 pounds for the South Carolina material. The strength ratio of the large to the small sticks is 0.77 for the fiber stress at elastic limit, 0.79 for the modulus of rupture, and 1.01 for the modulus of elasticity.

Moisture in longleaf pine timber, 10 × 12 inches in cross-section, after air-drying for one year yet contained 35 per cent. In large beams air-dried for two years, the drying did not penetrate to the center.

In ordinary seasoning, the strength of large sticks changes very little for the range of moisture usually met with in practice. Small pieces when kiln-dried increase in strength as much as 300 per cent, but large beams can not be dried out to the same extent. Moreover, the drying process often produces checks and ring shakes, the weakening effects of which more than counterbalance any gain in strength due to seasoning.

Bending strength: Longleaf pine; South Carolina; size 6 x 8 inches; span 15 feet; partially air dry; averaged: Moisture, 25 per cent; rings per inch, 14; specific gravity, dry 0.58; weight per cubic foot, as tested, 45.6 pounds; oven dry, 36.2 pounds; fiber stress at elastic limit, 3,800 pounds per square inch; modulus of rupture, 7,160 pounds per square inch; modulus of elasticity, 1,560,000 pounds per square inch; elastic resilience, 0.53 inch-pounds per cubic inch.

The crushing strength parallel to grain for longleaf pine is 4,800 pounds per square inch. The material tested contained 26.3 per cent moisture.

The compressive strength at elastic limit at right angles to grain is 572 pounds per square inch.

The shearing strength parallel to grain for small specimens is 973 pounds per square inch.

Longleaf pine finds a wide use in bridge, trestle, warehouse, and factory construction in the form of dimension timbers, posts, piles, and joists.

Inspection and grading: All lumber must be sound; commercial longleaf yellow pine shall be free from: Unsound, loose, and hollow knots, worm-holes and knot-holes, through shakes or round shakes that show on the surface, and shall be square edge unless otherwise specified.

A through shake is defined to be through or connected from side to side, edge to edge, or side to edge.

Where terms one-half or two-thirds heart are used they shall be construed as referring to the area of the face on which measured.

**Shortleaf pine** (*Pinus echinata*) has a variable, medium coarse grain; rings wide near the heart, followed by zone of narrow rings, mostly 10 to 15 to the inch; often fine grained. Color whitish to reddish brown. Sapwood is commonly about 4 inches of radius in trees 12 inches diameter. Resin moderately abundant; least pitchy; only near stumps, knots, and limbs.

Specific gravity of shortleaf pine has a possible range from 0.40 to 0.80 but more frequently between 0.43 to 0.53, averaging about 30 pounds per cubic foot.

Bending strength: Shortleaf pine; Arkansas; size, 8×12 inch; span, 15.0 feet; green; averaged: Moisture, 50 per cent rings per inch, 12; specific gravity, dry, 0.51; weight per cubic foot, as tested, 48 pounds; oven dry, 32 pounds; fiber stress at elastic limit, 3,420 pounds per square inch; modulus of rupture, 6,060 pounds per square inch; modulus of elasticity, 1,630,000 pounds per square inch.

Dry shortleaf pine; cross section 8×16 inches; span, 180 inches; averaged: Moisture, 17%; rings per inch, 12; fiber stress at elastic limit, 4,220 pounds per square inch; modulus of rupture, 6,030 pounds per square inch; modulus of elasticity, 1,517,000 pounds per square inch; calculated shear 398 pounds per square inch.

The effect of seasoning on the strength of large beams is well shown. Three sets of green North Carolina pine beams were dried in the open air in sunlight, in a kiln, and in a shed, respectively. The wood in the outer portion of the two sets of beams listed first was no doubt stronger than in the green condition. The beams failed in horizontal shear, however, before the added strength could be brought out, because of the presence of checks and shakes. A marked increase in strength was shown by the beams of select material that were carefully dried in a shed.

**Loblolly pine** (*Pinus taeda*) occurs in a belt along the Atlantic coast and the Gulf of Mexico, from Virginia to eastern Texas, extending inland from 50 to 300 miles. It is commonly sold in New York, Philadelphia, and other Eastern markets as North Carolina pine; it is generally forest grown timber of large size, with a large proportion of heartwood, fairly free from knots, and possessing a high order of structural value.

The grain of loblolly pine is variable, mostly very coarse, from 3 to 12 rings to the inch in structural lumber. Color is yellowish to reddish and orange-brown. Sapwood variable, 3 inches and upward of the radius in trees 12 inches or more in diameter. Resin abundant, more than shortleaf, less than longleaf.

Specific gravity of loblolly pine has a possible range of 0.40 to 0.80, but more frequently between 0.45 to 0.55, averaging about 31 pounds per cubic foot.

Bending strength of loblolly pine: cross-section, 8×16 inches; span, 180 inches; green; averaged: Moisture, 46 per cent; rings per inch, 6; fiber stress at elastic limit, 3,094 pounds per square inch; modulus of rupture, 5,394 pounds per square inch; modulus of elasticity, 1,406,000 pounds per square inch; calculated shear, 383 pounds per square inch.

Dry specimens of loblolly pine in cross-section, 8×16 inches; span, 180 inches; averaged: Moisture, 20.5 per cent; rings per inch, 7.4; fiber stress at elastic limit, 4,195 pounds per square inch; modulus of rupture, 6,734 pounds per square inch; modulus of elasticity, 1,619,000 pounds per square inch; calculated shear, 462 pounds per square inch.

Shortleaf and loblolly pines are used principally for building lumber, such as interior finish, flooring, ceiling, frames, and sashes, wainscoting, weather-boarding, joists, lath, and shingles; they are also used for construction purposes, in bridge and trestle work, and heavy building operations where the conditions are not such as to require longleaf. The introduction of preservative processes, which prevents or retards decay, has increased the use of shortleaf and loblolly for structural purposes.

Virginia pine is the timber cut in the northern portion of this loblolly belt; it is generally in small sticks, 8 by 8 inches or 10 by 10 inches in cross-section, almost entirely sapwood and of so rapid a growth that sometimes only four rings occur in 3 inches. This is second-growth timber, usually very knotty and of an inferior grade.

## TIMBERS OF THE PACIFIC COAST

**Douglas fir** (*Pseudotsuga taxifolia*) is the most important timber of the Northwest, and is more extensively used for structural purposes than any other single species. In the production of lumber it ranks second to the Southern yellow pines. Dimension timbers find a market throughout the Great Lake region and as far east as the Atlantic seaboard, for mining, dock, and dredging work, and for spars. It is also known commercially as yellow fir, red fir, Oregon pine, and Douglas spruce.

Its range extends from Lower California to central British Columbia, and from the Pacific Ocean to the Rocky Mountains. This timber reaches its best development in western Washington and Oregon, between the summit of the Cascade Mountains and the Pacific. Almost pure forests are found here in which the tree will average 5 or 6 feet in diameter at the butt, with a height up to 300 feet. It is possible, therefore, to obtain exceptionally large and long pieces for structural purposes. Sticks 24 inches square and up to 100 feet long are regularly listed and obtainable in the merchantable grades.

Small trees varying from 1 to 3 feet in diameter are unsurpassed for spars, owing to the straightness of the trunk, the small taper, and the great length obtainable. Douglas fir is almost exclusively used on the Pacific coast for piling for docks and foundations for heavy structures in soft ground. The standard dimensions for this purpose are 12 inches in diameter and from 60 to 70 feet long.

The sapwood in green logs from mature trees forms a narrow, light-colored ring, extending usually not more than 2 inches beneath the bark. In the seasoned timber, however, it can seldom be distinguished by color.

The color of the wood ranges from a light yellow to a pronounced red; the grain varies from as few as 4 or 5 rings per inch, in small trees or in heartwood, to a fine, even grain with upward of 40 rings per inch. The rings are usually strongly marked, the summerwood being very dense and dark, and the springwood much softer. The wide-ringed wood is somewhat spongy. Owing to the marked difference in the texture of the alternate rings and to the long, regular fiber, the wood splits easily, especially when dry.

Bending test: From an average of 216 tests of all grades, in sizes $8\times16$ to $5\times8$ inches in cross-section, on spans of 7 and 16 feet; 22 per cent moisture; 15 rings per inch; specific gravity, dry, 0.45; weight per cubic foot, as tested, 33.8 pounds (oven dry 28 pounds); the fiber stress at elastic limit was 4,859 pounds per square inch; modulus of rupture, 6,975 pounds per square inch; modulus of elasticity, 1,600,000 pounds per square inch; elastic resilience, 0.85 inch-pounds per cubic inch. The calculated shear is 269 pounds per square inch.

**Western hemlock** (*Tsuga heterophylla*) reaches its best development in Washington, in the region lying between the summit of the Cascade Mountains and the Pacific coast, but is also found from Alaska to central California and as far east as Idaho and Montana. The tree, where conditions best favor its development, reaches 4 feet in diameter at the butt and 200 feet in height. The trunk is straight and cylindrical, but does not readily clear itself of branches. This causes small knots in the timber and makes it impossible to obtain much clear lumber except from large trees.

The wood of the mature tree is hard, straight, and even grained, and nearly white in color. The wood does not split readily, and is light and tough. Knots are rather frequent, often dark brown to almost black in color, but usually tight and sound. The regular and even structure of the wood and the total absence of pitch render it capable of rapid kiln-drying at high temperature without injury. For flooring, molding, paneling, and all inside finish Western hemlock makes a superior lumber, not easily scratched, susceptible of a high polish, and of excellent wearing qualities.

Bending strength of Western hemlock from an average of 64 tests, of wood grown in Oregon and Washington: size $8\times16$ and $6\times8$ inches cross-section; span, 7 and 16 feet;

partially air-dried; averaged: Moisture 28 per cent; rings per inch, 13; specific gravity, dry, 0.42; weight per cubic foot, as tested, 33.2 pounds, oven dry, 26 pounds; fiber stress at elastic limit, 3,856 pounds per square inch; modulus of rupture, 5,992 pounds per square inch; modulus of elasticity, 1,351,000 pounds per square inch.

The crushing strength of partially air-dry Western hemlock averages 3,705 pounds per square inch.

The compressive strength at elastic limit, at right angles to the grain, partially air-dry, averaged 477 pounds per square inch.

The shearing strength parallel to the grain, in small pieces (3 × 1.5 inch area) averaged 746 pounds per square inch.

Western hemlock as a building material has met with much opposition. A strong prejudice exists against the name of hemlock, based upon the qualities of the Eastern species; large quantities of the timber are cut and sold under false or fictitious names, such as Alaska pine and Washington pine, spruce, or fir.

**Western larch** (*Larix occidentalis*) has not yet won a very important place among structural timbers. It has a limited range and will probably not be able to compete with the yellow pines and Douglas fir outside of the region in which it grows, principally Montana, Idaho, and Washington.

Bending strength: Western larch; cross-section, 8 × 16 inches; span, 180 inches; green; averaged: Moisture, 51 per cent; rings per inch, 25; fiber stress at elastic limit, 3,276 pounds per square inch; modulus of rupture, 4,632 pounds per square inch; modulus of elasticity, 1,272,000 pounds per square inch; calculated shear, 298 pounds per square inch.

Average strength values for compression parallel to grain, compression perpendicular to grain, and shearing tests on green material. Western larch: cross-section, 8 × 16 inches; span, 180 inches; averaged: Moisture, 18 per cent; rings per inch, 22; fiber stress at elastic limit, 3,343 pounds per square inch; modulus of rupture, 5,440 pounds per square inch; modulus of elasticity, 1,409,000 pounds per square inch; calculated shear, 349 pounds per square inch.

**Redwood** (*Sequoia sempervirens*) is one of the most desirable species from which heavy structural timbers may be secured, and the wood is also very slow-burning. The bulk of the material is cut in Humboldt and Mendocino counties, Cal. It is shipped in cargo lots to San Francisco and Southern California points and is distributed through these ports.

Redwood is a coniferous tree which grows to great size, aside from the famous group known as the "Mammoth Grove of Calaveras," to which redwood is related; it attains a diameter of 4 to 6 feet and upward, and a height of more than 200 feet. The wood has an even grain, of deep red color, cedar-like in appearance; it splits readily and evenly; it planes and polishes well. When cut radially the medullary plates give the wood a fine satiny luster.

Bending strength in 14 tests of redwood in cross-section 8 × 16 inches; span, 180 inches; green; averaged: Moisture, 86 per cent; rings per inch, 20; fiber stress at elastic limit, 3,734 pounds per square inch; modulus of rupture, 4,492 pounds per square inch; modulus of elasticity, 1,016,000 pounds per square inch; calculated shear, 300 pounds per square inch.

Average strength values for compression parallel to grain, compression perpendicular to grain, and shearing tests on air-dried redwood, 6 specimens of cross-section 8 × 16 inches; span, 180 inches; averaged: Moisture, 26.3 per cent; rings per inch, 22.4; fiber stress at elastic limit, 3,797 pounds per square inch; modulus of rupture, 4,428 pounds per square inch; modulus of elasticity, 1,107,000 pounds per square inch; calculated shear, 294 pounds per square inch.

## TIMBERS OF THE NEW ENGLAND AND LAKE STATES

**Norway pine** (*Pinus resinosa*) reaches its best development in the United States in the northern parts of Michigan, Wisconsin, and Minnesota, usually forming groves of a few hundred acres in extent on light, sandy loam or dry, rocky ridges. It ordinarily reaches a height of 75 feet and a diameter of 30 inches. The trunk is straight and clear

of branches. The wood is rather close-grained, is pale red when air-dried, and has a thin ring of sapwood. Norway pine is cut and sold with white pine in the Lake States under the name of Northern pine. It probably makes up about one-third of the present pine cut in this region.

Bending strength: Norway pine; Minnesota; size, 6 × 12 inches; span, 13.5 feet; green; averaged: Moisture, 48 per cent; rings per inch, 14; specific gravity, dry, 0.41; weight per cubic foot, as tested, 37 pounds; oven dry, 25 pounds; fiber stress at elastic limit, 2,550 pounds per square inch; modulus of rupture, 3,975 pounds per square inch; modulus of elasticity, 1,189,000 pounds per square inch; elastic resilience, 0.52 inch-pounds per cubic inch.

Tests of dry Norway pine: cross-section, 6 × 12 inches; span, 162 inches; averaged: Moisture, 17 per cent; rings per inch, 8; fiber stress at elastic limit, 2,968 pounds per square inch; modulus of rupture, 5,204 pounds per square inch; modulus of elasticity, 1,123,000 pounds per square inch; calculated shear, 286 pounds per square inch.

**Tamarack** (*Larix laricina*) reaches its best development north of the United States boundary, in Canada. It extends southward to northern Pennsylvania, northern Indiana and Illinois, and central Minnesota. In the United States tamarack occurs in cold, deep swamps, which it often clothes with forests of densely crowded trees rarely more than 40 or 50 feet in height. The maximum height of 60 feet and the maximum diameter of 20 inches are rarely attained in the United States. The trunk is straight and tapers rather rapidly; it clears itself readily of branches even when growing in fairly open stands. Tamarack lumber is cut principally in Wisconsin, Michigan, and Minnesota.

Bending strength: Tamarack; Minnesota; size, 6 × 12 inches; span, 162 inches; green; averaged: Moisture, 50 per cent; rings per inch, 14; specific gravity, dry, 0.48; weight per cubic foot, as tested, 45 pounds; oven dry, 30 pounds; fiber stress at elastic limit, 2,810 pounds per square inch; modulus of rupture, 4,562 pounds per square inch; modulus of elasticity, 1,219,000 pounds per square inch; elastic resilience, 0.62 inch-pounds per cubic inch.

Air-dried tamarack; cross-section, 6 × 12 inches; span, 162 inches; averaged: Moisture, 23 per cent; rings per inch, 15; fiber stress at elastic limit, 3,434 pounds per square inch; modulus of rupture, 5,640 pounds per square inch; modulus of elasticity, 1,330,000 pounds per square inch; calculated shear, 318 pounds per square inch.

Tamarack is at present a structural timber of minor importance and is used only locally in the Northern States.

**Spruce** is one of the trees of the genus *Picea*, of the pine family. It is found in British America, the northern United States, and in the Alleghanies to North Carolina. Its light, soft wood is largely made into lumber, and is used in construction, in ship-building, for piles, etc. Black spruce (*Picea nigra*) is a light, straight-grained wood used for building lumber, and is much used for masts and spars of ships. Red spruce (*Picea rubens*) is a stunted variety of black spruce, growing in swamps. White spruce (*Picea alba* or *canadensis*) is the commonest native spruce of the United States, having an extended range and utility. It is abundant in Canada, extending into northern New England, and reputed to be at its best in northern Montana. Its timber in commerce is not distinguished from that of the black spruce. It is used for joists and small forms of structural timbers. Spruce has a high value for paper pulp, and as a structural timber will doubtless never be of more than local importance.

Bending strength: Red spruce; cross-section, 2×10 inches; span, 144 inches; green; averaged: Moisture, 33 per cent; rings per inch, 22; fiber stress at elastic limit, 2,394 pounds per square inch; modulus of rupture, 3,566 pounds per square inch; modulus of elasticity, 1,180,000 pounds per square inch; calculated shear, 181 pounds per square inch.

Bending strength: White spruce; cross-section, 2×10 inches; span, 144 inches; green; averaged: Moisture, 41 per cent; rings per inch, 9; fiber stress at elastic limit, 2,239 pounds per square inch; modulus of rupture, 3,288 pounds per square inch; modulus of elasticity, 1,081,000 pounds per square inch; calculated shear, 166 pounds per square inch.

## TIMBER TESTS

In bending tests the specimens were supported near the ends, and the load applied at two points, each located at one-third of the length of the span from the end supports; a method which reproduces closely the conditions to which a beam is subjected in structural work. Four factors were calculated from the data derived, all in terms of pounds per square inch:

(a) Fiber stress at elastic limit: This is the greatest stress that can occur in a beam loaded with an external load from which it will recover without permanent deflection.

(b) Modulus of rupture: This is the greatest computed stress in a beam loaded with a breaking load.

(c) Modulus of elasticity: This is a factor computed from the relation between load and deflection within the elastic limit, and represents the stiffness of the wood fiber.

(d) Longitudinal shear: This is the stress tending to split the beam lengthwise along its neutral plane when under maximum load.

**Compression Parallel to Grain.**—The specimens were set upright on the platform of the testing machine and crushed endwise. Observations of amount of load and deflection, or compression, were made as in the bending tests.

**Compression Perpendicular to Grain.**—The tests were made by laying each block on its side on the platform of the machine, and applying pressure to an iron plate resting on the block's upper side. The test corresponds to the action of a rail on a cross-tie, or a floor joist on a supporting beam. Readings of the load and the corresponding deflection or crushing were taken up to and slightly beyond the elastic limit. From these data the compressive strength at elastic limit in pounds per square inch was calculated.

**Shearing.**—These tests were made on small, clear blocks with a projecting lip 2 by 3 inches in section. The blocks were held firmly, and the lip sheared off parallel to the grain. The load required to shear off the lip was calculated in pounds per square inch.

## SECTION 5

# STEEL BARS, PLATES, SHAPES, BOLTS, RIVETS

## NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form a part of these specifications.

2. **Ingots.**—Ingots will be divided into three clssses: (a) Top poured; (b) Bottom poured; (c) Fluid compressed.

3. **Bored Ingots.**—If bored ingots are ordered, the wall of the ingot must be at least one and one-half times the thickness of the wall of the forging to be made therefrom.

4. **Discards.**—(a) From class (a) ingots only so much will be used as remains after at least 5 per cent of the total weight has been discarded from the bottom, and at least 30 per cent of the total weight from the top.

(b) From class (b) ingots only so much will be used as remains after at least 5 per cent of the total weight has been discarded from the bottom, and at least 20 per cent of the total weight from the top.

(c) From class (c) ingots, when parts are forged solid, only so much will be used as remains after at least 5 per cent of the total weight has been discarded from the bottom, and at least 20 per cent of the total weight from the top.

(d) When forgings are to be made from bored fluid compressed ingots at least 3 per cent of the total weight of the ingot shall be discarded from the bottom and at least 10 per cent of the total weight from the top.

(e) If ingots are cast in any unusual manner, the amount of minimum discard from them will be determined by the bureau concerned.

5. **Test.**—Ingots made by steel manufacturers and to be forged or rolled into finished objects by establishments other than those manufacturing them will be subjected to chemical test.

6. **Slabs, Blooms, and Billets.**—The line between blooms and billets to be drawn at 36 square inches cross-section. Rounds shall be classed as blooms or billets if they are to be reforged or retreated.

7. **Ordering.**—Slabs, blooms, and billets will be ordered by grade with reference to the classifications as contained in the Navy Department's latest specifications for hull and engine forgings.

8. **Material.**—Slabs, blooms, and billets for the use of the Navy Department shall be manufactured from open-hearth, crucible, or electric-furnace steel, and shall be rolled or forged from ingots of at least four times the cross-section of the finished slab, bloom, or billet.

9. **Tests When Material is Not to be Reforged.**—Slabs, blooms, and billets of carbon, nickel, and alloy steel and which are not to be reforged or retreated shall be tested at the place of manufacture, and shall comply with the chemical and physical requirements of their grades, as contained in the Navy Department's latest specifications for hull and engine forgings. For identification this material shall be stamped with the number of the heat or ingot.

10. **Tests When Material is to be Reforged.**—(a) Slabs, blooms, and billets of carbon and nickel steel and which are to be reforged or retreated by establishments other than those manufacturing them shall be accepted on the chemical requirements for the grade as specified. In case of ordering same according to the requirements of forgings for which they are intended a reduction of 10 per cent on the required percentage of elongation and reduction of area shall be allowed by the inspector and the bending test will not be required. This material shall be plainly stamped with the forgings and grade number and the words "For reforging."

(b) Slabs, blooms, and billets of alloy steel and which are to be reforged or retreated by establishments other than those manufacturing them shall be accepted on the chemical requirements for the grade as specified. This material shall be plainly stamped with the forging and grade number and the words "For reforging." The manufacturer shall furnish the inspector with a description of the heat treatment necessary to produce the physical requirements of the grade ordered.

11. **Surface Inspection.**—All slabs, blooms, and billets shall be free from injurious surface defects, shall be reasonably straight and free from twist, and shall not vary from the transverse dimensions specified more than 3 per cent, under or over.

12. **Test Bars.**—(a) The standard tensile-test bar, 0.505 inch in diameter and 2 inches between measuring points, will be used.

(b) The standard bar for the cold-bending test shall be of rectangular cross-section, 0.5 inch by 1 inch. The edges may be rounded off to a radius of $\frac{1}{16}$ of an inch.

13. **Location of Test Bars.**—Tensile and cold-bending test pieces shall be taken in the direction of the greatest working of the slab, bloom, or billet and on the line of greatest width, at one-half the distance from the center to the edge of the slab, bloom, or billet.

14. **Tests.**—In all cases where physical tests are required at the place of manufacture the slabs, blooms, and billets shall be tested by heats (if treated together; otherwise from each lot of each heat so treated), four longitudinal tensile and two longitudinal cold-bending test pieces being selected, each from a different object; but if less than sixteen pieces are made from one heat, then one cold-bending and two tensile test pieces shall be selected; but if there is one slab, bloom, or billet from a heat, one longitudinal textile and one longitudinal cold-bending test piece will suffice, either or both of which to be taken from the upper or lower end, at discretion of the inspector.

15. **Chemical Analysis.**—A chemical analysis will be made by the contractor of each heat and the sample may be taken from a physical test piece or drilled from the slab, bloom, or billet at the point designated in paragraph 13 as the location for the test piece.

# BOILER PLATES

## NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Physical and Chemical Properties.**—The physical and chemical characteristics of steel boiler plate are to be in accordance with the table on opposite page.

### TESTS

3. **Number of Tests.**—One longitudinal tensile test piece and one bending test piece (transverse for Class "A" and Class "B" and longitudinal for Class "C" boiler plate) shall be cut from each plate as rolled at such points as may be designated by the inspector. The cold-bending test pieces may have their corners rounded to a curve the radius of which is equal to one-fourth the thickness of the plate.

4. **Additional Tests.**—The inspector may require from time to time such additional tests as he may deem necessary to determine the uniformity of the material.

5. **Rejection on Delivery.**—Boiler plate may be rejected at a navy yard or other places of delivery for surface or other defects either existing on arrival or developed in working or storage, even though the material may have passed the required inspection at the place of manufacture.

### FINISH

6. **Surface Inspection.**—Boiler plates shall be free of all slag, foreign substances, brittleness, laminations, hard spots, brick or scale marks, scabs, snakes, or other injurious defects.

| Class | Material | Tensile Strength (Pounds per Square Inch) | Minimum Elastic Limit (Pounds per Square Inch) | Elongation (Per Cent in 8 Inches) | Maximum Percentage of— | | Without Showing Cracks or Flaws Must Cold Bend About an Inner Diameter— |
|---|---|---|---|---|---|---|---|
| | | | | | P | S | |
| A | Open-hearth steel | 65,000 to 75,000 | ½ T. S. | 22 | 0.04 | 0.035 | Equal to thickness of plate and through 180° for plates 1 inch in thickness and under and equal to one and one-half times the thickness through 180° for plates over 1 inch in thickness. |
| B | Do. | 58,000 to 65,000 | ½ T. S. | 25 | .04 | .035 | Flat back through 180° for plates under 1 inch in thickness and equal to thickness of plate through 180° for plates 1 inch and over in thickness. |
| C | Open-hearth or Bessemer steel | To be in accordance with specifications for flange and boiler steel adopted by the Association of American Steel Manufacturers, revised 1903. | | | | | |

Notes.—When the finished plate is ¼ inch or less the elongation shall be measured on an original length of sixteen times the thickness of the plate tested.

When plates are ordered to gauge, United States standard gauge will be used.

7. **Shearing.**—Boiler plates shall not be sheared closer to finished dimensions than once the thickness of the plate along each end and one-half the thickness of the plate along each side. This allowance shall be made by the contractor in his order, and the manufacturer shall shear to the ordered dimensions.

8. **Variation in Thickness. Tolerance.**—A tolerance of 0.01 inch below the ordered gauge will be permitted for plates up to and including 100 inches in width, and for plates over 100 inches in width a tolerance of 0.015 inch will be allowed, measured in each case at the thinnest point.

9. **Weight Variation Tolerance.**—For all plates ordered to gauge there will be permitted an average excess of weight over the calculated weight equal in amount to that specified in the table on the following page.

10. **Marking and Stamping.**—Each plate shall be stamped with heat number figures to be not less than ½ inch long, and shall have size and order number plainly marked with white paint.

11. **Inspection Stamps.**—Plates which have passed inspection must show the U. S. anchor and other stamps necessary for identification, encircled by white paint marks.

## REHEATING

12. **Boiler-Drum Tube Sheets, Drumheads, Etc.**—Boiler-drum tube sheets, drumheads, headers, nozzles, and man- and hand-hole plates which are formed from boiler plate shall be formed hot.

13. **Temperatures of Reheating.**—The inspector shall see that the proper temperature is used for forming boiler parts from material and that the material is not overheated.

ALLOWANCES FOR OVERWEIGHT FOR PLATES WHEN ORDERED TO GAUGE

| Thickness of Plate, in Inches | Width of Plate in Inches | | | | | | |
|---|---|---|---|---|---|---|---|
| | Up to 50 | 50 to 70 | Over 70 | Up to 75 | 75 to 100 | 100 to 115 | Over 115 |
| | Percentage Allowed | | | | | | |
| Under $\frac{5}{32}$ | 10 | 15 | 20 | ... | ... | ... | .. |
| $\frac{5}{32}$ up to $\frac{3}{16}$ | $8\frac{1}{2}$ | $12\frac{1}{2}$ | 17 | ... | ... | ... | .. |
| $\frac{3}{16}$ up to $\frac{1}{4}$ | 7 | 10 | 15 | ... | ... | ... | .. |
| $\frac{1}{4}$ | ... | ... | .. | 10 | 14 | 18 | .. |
| $\frac{5}{16}$ | ... | ... | .. | 8 | 12 | 16 | .. |
| $\frac{3}{8}$ | ... | ... | .. | 7 | 10 | 13 | 17 |
| $\frac{7}{16}$ | ... | ... | .. | 6 | 8 | 10 | 13 |
| $\frac{1}{2}$ | ... | ... | .. | 5 | 7 | 9 | 12 |
| $\frac{9}{16}$ | ... | ... | .. | $4\frac{1}{2}$ | $6\frac{1}{2}$ | $8\frac{1}{2}$ | 11 |
| $\frac{5}{8}$ | ... | ... | .. | 4 | 6 | 8 | 10 |
| Over $\frac{5}{8}$ | ... | ... | .. | $3\frac{1}{2}$ | 5 | $6\frac{1}{2}$ | 9 |

The weight of 1 cubic inch of rolled steel is assumed to be 0.2833 pound.

14. **Flanges.**—All flanges must be carefully examined for defects before and during the pressure test of the boiler.

## INSPECTION FACILITIES

15. **Mill Inspection.**—The material shall be inspected at the mill unless special authority to the contrary is given.

16. **Access to Manufacturing Plant.**—The Navy Department shall have the right to keep inspectors at the place of manufacture, and these inspectors shall have free access at all times to all parts of the manufacturing plant and be permitted to examine the raw material and to witness the process of manufacture.

17. **Testing Machine and Other Appliances.**—The manufacturer shall furnish all facilities for inspecting and testing the weight and quality of all material at the mill where it is manufactured. He shall furnish a suitable testing machine for testing the specimens as well as prepare the specimens for the machine free of cost.

18. **Inspection Office, Etc.**—The manufacturer shall furnish free of cost the inspectors with such facilities as may be necessary for the proper transaction of their business as agents of the Government.

# STEEL PLATES FOR HULLS AND HULL CONSTRUCTION FOR THE UNITED STATES NAVY

1. **General Requirements.**—The "General Specifications for the Inspection of Material," of latest issue by the Navy Department, shall form a part of these specifications, and must be complied with as to material, method of inspection, and all other requirements therein.

2. **Finish.**—Plates shall be flat, free from all injurious defects, and shall have a workmanlike finish.

3. **Physical and Chemical Requirements.**—The physical and chemical requirements and kind of material for plates shall be in accordance with the table on opposite page.

| Grade | Material | Minimum Tensile Strength | Minimum Elongation | Maximum Amount of— P. | Maximum Amount of— S. | Cold Bend |
|---|---|---|---|---|---|---|
| | | *Pounds per Sq. Inch* | *Per Cent* | *Per Ct.* | *Per Cent* | |
| Soft or flange steel | Open-hearth carbon steel | 50,000 | 30 | 0.05 acid. .04 basic | 0.05 | 180° flat on itself. |
| Medium steel | Open-hearth carbon steel | 60,000 | 25 | 0.05 acid. .04 basic | 0.05 | For test specimens below $\frac{3}{4}$ inch in thickness, 180° flat on itself for longitudinal, and 180° to diameter of one thickness for transverse. For test specimens $\frac{3}{4}$ inch thickness and above, the bends will be 180° to a diameter of one thickness for longitudinal, and two thicknesses for transverse specimens. |
| High tensile steel | Open-hearth carbon, nickel, or silicon steel | 80,000 | 20 | 0.05 acid. .04 basic | 0.05 | 180° to a diameter of one and one-half thicknesses for longitudinal, and 180° to a diameter of two and one-half thicknesses for transverse. |
| Common steel (c) | Open-hearth or Bessemer steel | 55,000 | 22 | No chemical analysis required | | 180° to a diameter of one thickness. |

4. **Test Specimens.**—(a) Elongation.—For plates up to and including 5.1 pounds per square foot, the elongation shall be measured on a length of 2 inches; over 5.1 pounds per square foot, up to and including 7.65 pounds, in 4 inches; over 7.65 pounds per square foot, up to and including 10.2 pounds, in 6 inches; over 10.2 pounds per square foot, and under 60 pounds per square foot in 8 inches. The test specimens may be either Type II or Type III.

(b) For plates 60 pounds per square foot and over the elongation shall be measured in 2 inches, using the standard 2-inch turned specimen (Type I), in which case the minimum shall be 27 per cent for medium steel and 22 per cent for high tensile steel.

(c) Bending.—The bending test specimens shall conform to "General Specifications," paragraph 21.

(d) Permissible Variations.—In melt and individual tests of plates under 60 pounds per square foot the specimens for tensile tests shall be required to average the requirements of the grade of steel they represent; but no test shall fall more than 3,000 pounds in tensile strength, or 2 units of per cent in elongation below the requirements for steel of the grade. An additional allowance for transverse specimens shall be a deduction of 1 unit of per cent in elongation for each increase of $\frac{1}{8}$ inch in thickness above $\frac{3}{4}$ inch; provided that the minimum elongation for any such transverse specimen shall be 20 per cent for medium steel and 16 per cent for high tensile steel.

(e) For plates 60 pounds per square foot and over, a variation in tensile strength only, of 3,000 pounds below the requirement for steel of the grade, will be allowed.

5. **Common Steel.**—(a) Common steel may be rolled from any stock on hand, and the stamping of serial numbers on separate pieces may be omitted, provided that all other information required by these specifications, such as melt and charging records, etc., be supplied to the inspector, to enable him to select test specimens.

(b) Two test specimens shall be taken from each melt of finished material—one for tension and one for bending.

(c) Common steel plates shall, in addition to other marks prescribed, have painted conspicuously on each plate the letter "C," not less than 12 inches in height. All invoices or reports of material shipped shall be plainly marked "Common."

6. **Material Presented for Test.**—(a) Plates under 60 pounds per square foot may be tested as individual plates or by melts. Plates 60 pounds per square foot and over shall be tested as individuals. On individual test the plate is accepted or rejected on the result of the tests representing that plate only. On melt test all the material from the same melt is accepted or rejected on the result of the tests representing the melt, subject, however, to such special tests as may be considered necessary by the inspector.

(b) When a melt is rolled and presented for test as a melt, six plates shall be selected by the inspector for test, each plate from a different ingot, if practicable. The plates shall be so selected as to represent the topmost and bottommost parts of the ingots. When the difference in gauge of the plates rolled is such that six plates will not properly represent the melt, sufficient additional plates shall be selected for test to give satisfactory information of the physical characteristics of all the gauges rolled.

(c) When a melt is presented for test preliminary to rolling, six plates shall be rolled from slabs or ingots which may be selected by the inspector, each plate being from a different slab, and when practicable from a different ingot. The plates shall be selected to represent the topmost and bottommost parts of the ingots. Plates rolled for such a test shall not vary from the maximum to the minimum gauge—more than 2.7 pounds per square foot for plates 10.2 pounds per square foot and under; more than 5 pounds per square foot for plates above 10.2 pounds, including 30.6 pounds per square foot; more than 10 pounds per square foot for plates over 30.6 pounds per square foot. Plates subsequently rolled from such a melt shall be of the gauges tested or intermediate gauges, except that the inspector may authorize the rolling of gauges not more than 25 per cent above and below the gauges tested in the case of plates 10.2 pounds per square foot and under, and not more than 5 pounds per square foot above and below in the case of plates over 10.2 pounds per square foot. The inspector shall satisfy himself that the material rolled has received practically the same treatment as the test plates, especially as to the amount of working temperature during finishing, and amount of discard from the ingot.

(d) Plates rolled to gauges other than those authorized on the melt test will be tested as individuals.

7. **Number of Tests.**—(a) Melt Tests.—One tensile test specimen shall be located by the inspector on each of four of the plates submitted for test. Two of the test specimens shall be cut longitudinally, that is, in the direction of greatest working, and two transversely, that is, in the direction of least working. These four test specimens shall be selected so as to represent the upper and lower and intermediate gauges rolled, as specified in paragraph 6 (c). Two bending test specimens shall be located by the inspector on each of the two remaining plates, one test specimen on each plate being cut longitudinally and one transversely. These bending test specimens shall be taken from a plate representing the topmost part of the ingot.

(b) Individual Tests.—When a plate under 60 pounds per square foot is submitted for individual test, three test specimens shall be located by the inspector. Two of these shall be tensile specimens, one to be taken longitudinally, and one transversely, one being from each end of the plate. The third, a transverse cold bend, shall be taken from the opposite end from which the transverse tensile specimen is taken.

(c) For plates 60 pounds per square foot and over two test specimens shall be located by the inspector. One of these will be a tensile specimen, which will represent the material nearest the bottom of the ingot; the other will be a cold-bend specimen, which will be taken from the opposite end of the plate from the tensile specimen. The

tensile test specimen shall be cut longitudinally and the bend test specimen shall be cut transversely. Both specimens shall be cut from the ends of the plate midway between the center and the outer edge.

8. **Universal Plates.**—(a) Universal plates shall be in accordance with the foregoing requirements for steel of the grade specified except that the melt and individual tests shall be as given in the following.

(b) MELT TESTS.—One tensile test specimen shall be located by the inspector on each of four of the plates submitted for test. All of the test specimens shall be cut longitudinally, that is, in the direction of greatest working. One cold-bending test specimen, cut longitudinally, shall be located by the inspector on each of the two remaining plates.

If practicable, both cold-bending test specimens shall be cut from the end representing the top of the ingot.

(c) INDIVIDUAL TESTS.—When a plate is submitted for individual test, one tensile and one cold-bending test specimen, both cut longitudinally, shall be located by the inspector. The tensile test specimen shall be located to represent the material nearest the bottom of the ingot, and the cold-bending test specimen will be taken from the opposite end of the plate.

9. **Figured Plates.**—(a) CLASS A.—These plates shall conform in all respects to the requirements of medium steel as outlined above.

(b) CLASS B.—These plates shall conform in all respects to the requirements of common steel as called for above.

10. **Galvanized Plates.**—(a) PHYSICAL AND CHEMICAL REQUIREMENTS.—Plates to be galvanized shall meet the requirements for steel of the grade specified before galvanizing and shall conform to the permissible variations in weight and gauge before galvanizing.

(b) FREEDOM FROM SURFACE DEFECTS.—Galvanized plates must be thoroughly and evenly galvanized; of a bright appearance; free from pits, blisters, and other defects; and must be commercially flat. No rerolling of the plates after leaving the galvanizing bath will be permitted, except for the purpose of straightening. The coating must not break off when scraped with a knife or if the plate is bent 90°.

(c) SAMPLES FROM GALVANIZING BATH.—The galvanizing material must show at least 98 per cent pure zinc, determined from a sample taken at random by the inspector, from the upper half of the galvanizing bath. The sample may be taken at any time, provided the manufacturer agrees to have the sample represent the coating for the order; otherwise, when the inspector has been unable to secure a sample of the bath used for the order, the purity of the bath may be established by a sample of galvanized plate taken at random from the finished material.

(d) AMOUNT OF COATING.—The increase in weight due to galvanizing shall not exceed $2\frac{3}{4}$ ounces nor shall it be less than 2 ounces per square foot of surface coated. The determination of the amount of coating per square foot shall preferably be made by establishing the practice of the firms, at convenient intervals, by weighing plates as follows: First, weight in bulk of selected plates in the black, after pickling. Second, weight of the same selected plates after galvanizing. If this course cannot be pursued, a selected sample from the galvanized plates for the order, of 2 square feet of surface, will be sent to a Government laboratory, at the expense of the contractor, where determination will be made of the amount of zinc coating per square foot.

11. **Permissible Variations in Weight and Gauge.**—The maximum permissible variations in weight and gauge, applicable to single plates, will be in accordance with the tables on following page.

12. **Character of Material for Certain Purposes.**—(a) Narrow plates, or flats, intended for seam straps or similar purposes may be rolled on universal or bar mill and tested in accordance with requirements for universal plates.

(b) The use of universal rolled plates will not be permitted for butt straps or for any purpose where the transverse strength of the material is of particular importance.

**Note for General Storekeepers.**—Plates or sheets 0.141 inch and under in thickness should be ordered under these specifications only when they are for structural purposes where strength and gauge are important; otherwise such plates should be ordered under

the latest issue of specifications for black and galvanized sheet steel, No. 47S8, of the latest sub-letter.

(a) PLATES LESS THAN 10 POUNDS PER SQUARE FOOT

| Weight Ordered (Pounds per Square Foot) | Allowable Variation in Weight (Per Cent) | Allowable Undergauge at Edge (Per Cent) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Up to 40 Inches, Inclusive | Over 40 Inches, to 50 Inches, Inclusive | Over 50 Inches, to 60 Inches, Inclusive | Over 60 Inches, to 70 Inches, Inclusive | Over 70 Inches, to 80 Inches, Inclusive | Over 80 Inches, to 90 Inches, Inclusive | Over 90 Inches, to 100 Inches, Inclusive | Over 100 Inches |
| Up to 5 | 3 over. 5 under | 12 | 15 | 18 | 21 | 24 | .. | .. | .. |
| 5 inclusive to 7½ exclusive | " | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 |
| 7½ inclusive to 10 exclusive | " | 8 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |

(b) PLATES 10 POUNDS PER SQUARE FOOT AND OVER

| Weight Ordered (Pounds per Square Foot) | Allowable Variation in Weight (Per Cent) | Allowable Undergauge at Edge (Per Cent) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Up to 66 Inches, Inclusive | Over 66 Inches, to 80 Inches, Inclusive | Over 80 Inches, to 90 Inches, Inclusive | Over 90 Inches, to 100 Inches, Inclusive | Over 100 Inches, to 110 Inches, Inclusive | Over 110 Inches, to 120 Inches, Inclusive | Over 120 Inches |
| 10 inclusive to 12½ exclusive | 3 over. 5 under | 10 | 11 | 12 | 13 | 14 | 18 | .. |
| 12½ inclusive to 15 exclusive | 2 over. 3 under | 8 | 9 | 10 | 11 | 12 | 14 | 16 |
| 15 inclusive to 17½ exclusive | " | 6 | 7 | 8 | 9 | 10 | 11 | 13 |
| 17½ inclusive to 20 exclusive | " | 5 | 5 | 6 | 7 | 8 | 9 | 10 |
| 20 inclusive to 25 exclusive | " | 4 | 5 | 5 | 5 | 6 | 7 | 8 |
| 25 inclusive to 30 exclusive | " | 3 | 3 | 3 | 4 | 5 | 5 | 6 |
| 30 inclusive to 40 exclusive | " | 3 | 3 | 3 | 3 | 3 | 4 | 5 |
| 40 and up | " | 2 | 2 | 2 | 3 | 3 | 3 | 4 |

# STEEL SHAPES FOR HULLS AND HULL CONSTRUCTION

## NAVY DEPARTMENT

1. **General Requirements.**—"General Specifications for Inspection of Steel and Iron Material, General Specifications, Appendix I," issued June, 1912, shall form a part of these specifications, and must be complied with in all respects.

2. **Finish.**—All shapes shall be true to section, free from injurious defects, and shall have a workmanlike finish.

3. **Physical and Chemical Requirements.**—(a) All shapes shall be of uniform quality. The physical and chemical requirements of the various grades of material for shapes shall be in accordance with the following table:

| Grade | Material | Minimum Tensile Strength per Square Inch | Minimum Elongation in 8 Inches (b) | Maximum Amount of— | | Cold Bend |
|---|---|---|---|---|---|---|
| | | | | P. | S. | |
| | | *Pounds* | *Per Ct.* | *Per Ct.* | *Per Ct.* | |
| Soft or flange steel | Open-hearth carbon steel | 48,000 | 30 | *Acid* 0.05 *Basic* .04 | 0.05 | 180° flat on itself. |
| Medium steel | Open-hearth carbon steel | 60,000 | 25 | *Acid* 0.05 *Basic* .04 | 0.05 | For test pieces below ¾ inch in thickness, 180° flat on itself. For test pieces ¾ inch or more in thickness the bends will be 180° to a diameter of one thickness. |
| High tensile steel | Open-hearth carbon nickel, or silicon steel | 80,000 | 20 | *Acid* 0.05 *Basic* .04 | 0.05 | 180° to a diameter of one and one-half thicknesses. |
| Common steel (c) | Open-hearth or Bessemer steel | 56,000 | 22 | No chemical analysis required | | 180° to a diameter of one thickness. |

(b) Elongation.—For shapes, the legs or webs of which have a nominal thickness ⅛ inch or less, elongation will be measured in 2 inches; over ⅛ inch nominal thickness, to and including $\frac{3}{16}$ inch, in 4 inches; over $\frac{3}{16}$ inch nominal thickness, to and including ¼ inch, in 6 inches; and over ¼ inch nominal thickness, in 8 inches.

4. **Tensile Tests (Except for Common Steel).**—Shapes shall be tested by lots (or singly); a lot consisting of all the shapes rolled from a particular melt at a continuous rolling into sections, the nominal gauges of the webs or legs of which do not vary more than ⅛ inch from the maximum to the minimum gauge. Four longitudinal test pieces shall be prepared from each lot, each specimen being from a separate shape, and, if practicable, from different ingots. All of these specimens must meet the requirements for the grade of steel specified. No lot will be accepted if there is a difference of more than 10,000 pounds in tensile strength between any two of the four specimens.

5. **Bending Tests (Except for Common Steel).**—Two cold-bend specimens shall be taken from each lot, each from a different shape. These specimens shall meet the requirements of the specified grade of steel without sign of fracture on the outer curve. If one of these specimens fail, each shape rolled from the lot must pass the cold-bending test before being cut to ordered length.

6. **Physical Tests for Common Steel.**—Common steel may be rolled from any stock on hand, but all informatiom required by these specifications, such as melt and charging records, etc., shall be supplied to the inspector to enable him to select test specimens. Two specimens shall be taken from each melt of finished material—one for tension test and one for bending test.

7. **Opening and Closing Tests.**—Opening and closing tests will be made at the option of the inspector on individual angles, Zee bars, Tee bars, I beams and channels which show evidence of mechanical defects or overheating, if in the opinion of the inspector the nature and extent of the defects need confirmation by such tests. The opening test shall consist of opening the section out flat while cold and the closing test

shall consist of closing the section down flat on itself while cold. Under these tests the material shall not crack or tear.

8. **Test of a Single Shape.**—In case of a single shape one tensile and one cold-bending test will be made. These tests must meet the requirements for the grade of steel specified.

9. **Tolerances.**—Shapes of 6 pounds per linear foot or less will be accepted if the weights vary 3 per cent above and 5 per cent below the specified weight. Shapes over 6 pounds per linear foot will be accepted if the weights vary 2 per cent above or 3 per cent below the specified weights.

10. **Marking Common Shapes.**—Common shapes shall, in addition to the other marks prescribed, have painted conspicuously on each shape the word "Common." All invoices or "Reports of Material Shipped," covering this class of material, shall be plainly marked with the word "Common."

## BLACK AND GALVANIZED SHEET STEEL

### NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. These specifications cover sheets of 0.141 inch in thickness and thinner.

3. **General Requirements.**—Sheets shall be made of the very best soft sheet steel; to stand double-seam purposes.

4. (a) To be free from all injurious defects, and to be free also from excessive scale and to be commercially flat and reasonably free from waves and buckles.

(b) To be of the finest working quality and meet the allowances for thickness and weights given below.

(c) Bundling.—Sheets 0.063 inch thick or thicker, weighing 60 pounds each or over, are not to be bundled. All other sheets to be delivered in commercial bundles fastened with three iron or steel straps not to exceed 1¼ inches in width and not thicker than ⅛ inch. When sheets exceed 120 inches in length, an extra strap may be required by the inspector.

(d) Payment.—Gross weight will be paid for.

(e) Marking.—Outside surface of the top sheet of each bundle (or single sheet when not bundled) shall be plainly marked to show the number and size of sheets, weight per square foot, and gross weight.

(f) **Tolerances.**—When not otherwise specified, allowance over the width and length ordered will be permitted, as shown in the table below. Sheets required to be closer in dimensions will be ordered as "resquared."

(g) The agreement with thickness ordered is to be established by the weight. Each sheet shall be of practically uniform thickness.

(h) A variation in weight of sheets of 5 per cent, plus or minus, will be allowed.

5. **Regular Sizes.**—(a) Regular sizes of sheets are as follows, those italicized being most used.

| Thickness, in Inches | Width | Length | Maximum Variation in Length (Plus) | Maximum Variation in Width (Plus) |
|---|---|---|---|---|
| | *Inches* | *Inches* | *Inch* | *Inch* |
| 0.141 to 0.063, inclusive | 24, 26, 28, 30, *36*, 40, 42, 48 | 72, 84, *96*, 120, 144 | ½ | ¼ |
| 0.056 to 0.025, inclusive | 24, 26, 28, 30, *36* | 72, 84, *96*, 120, 144 | ¾ | ¼ |
| 0.022 to 0.016, inclusive | 24, 26, 28, 30 | 72, 84, *96*, 120, 144 | ¾ | ¼ |
| 0.014 to 0.013, inclusive | 24, 26, 28, 30 | 72, 84, *96*, 120 | ¾ | ¼ |

(b) Maximum Sizes.—Maximum sizes of sheets are as follows:

| Black | | Galvanized, and Black Thinner Than 0.063 Inch | |
|---|---|---|---|
| Thickness | Dimensions | Thickness | Dimensions |
| *Inch* | *Inches* | *Inch* | *Inches* |
| 0.141............ | 24 x 240 or 66 x 180 | 0.141 to 0.038, inclusive..... | 48 x 144 |
| 0.125 and 0.109... | 24 x 228 or 66 x 180 | 0.034 to 0.025, inclusive.... | 28 x 144 or 48 x 120 |
| 0.094 and 0.078... | 54 x 156 | 0.022 and 0.019............ | 28 x 144 or 44 x 120 |
| 0.070 and 0.063... | 54 x 156 | 0.017..................... | 28 x 144 or 42 x 120 |
| | | 0.016 to 0.013, inclusive.... | 28 x 144 or 36 x 120 |

6. Weights for black and galvanized sheets:

(a) These weights are the weights adopted commercially for sheets of corresponding thicknesses and are approximate weights.

| Thickness, in Inches | Weight per Square Foot | | | | Thickness, in Inches | Weight per Square Foot | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Galvanized | | Black | | | Galvanized | | Black | |
| | *Lbs.* | *Ozs.* | *Lbs.* | *Ozs.* | | *Lbs.* | *Ozs.* | *Lbs.* | *Ozs.* |
| 0.141 | (5.781) | 92.5 | (5.625) | 90 | 0.034 | (1.531) | 24.5 | (1.375) | 22 |
| .125 | (5.156) | 82.5 | (5.00 ) | 80 | .031 | (1.406) | 22.5 | (1.25 ) | 20 |
| .109 | (4.531) | 72.5 | (4.375) | 70 | .028 | (1.281) | 20.5 | (1.125) | 18 |
| .094 | (3.906) | 62.5 | (3.75 ) | 60 | .025 | (1.156) | 18.5 | (1.0 ) | 16 |
| .078 | (3.281) | 52.5 | (3.125) | 50 | .022 | (1.031) | 16.5 | ( .875) | 14 |
| .070 | (2.968) | 47.5 | (2.812) | 45 | .019 | ( .906) | 14.5 | ( .75 ) | 12 |
| .063 | (2.656) | 42.5 | (2.50 ) | 40 | .017 | ( .843) | 13.5 | ( .687) | 11 |
| .056 | (2.406) | 38.5 | (2.25 ) | 36 | .016 | ( .781) | 12.5 | ( .625) | 10 |
| .050 | (2.156) | 34.5 | (2.00 ) | 32 | .014 | ( .718) | 11.5 | ( .562) | 9 |
| .044 | (1.906) | 30.5 | (1.75 ) | 28 | .013 | ( .656) | 10.5 | ( .50 ) | 8 |
| .038 | (1.656) | 26.5 | (1.50 ) | 24 | .... | ...... | ... | ...... | .. |

Note for General Storekeepers.—Requisitions should state the material desired, black or galvanized, the width, length, and weight per square foot. In ordering material, where possible, regular sizes will be asked for, and where special sizes are required the maximum limits will not be exceeded.

7. **Galvanized Sheets, Freedom from Defects.**—Galvanized sheets must be thoroughly and evenly galvanized, of a bright appearance, devoid of blisters, ragged edges or other defects, reasonably free from buckles, and commercially flat. The zinc coating must not flake or peel off when scraped with a knife or when the sheet is bent sharply at right angles.

8. **Thickness.**-

| Thickness, in Inches | Maximum Sizes | Minimum Zinc Coating per Square Foot for Galvanized Plates |
|---|---|---|
| | *Inches* | *Ounces* |
| 0.141 to 0.038, inclusive | 48 x 144 | 1.65 |
| 0.034 to 0.025, inclusive | 28 x 144<br>48 x 120 | 1.50 |
| 0.022 and 0.019 | 28 x 144<br>44 x 120 | 1.40 |
| 0.017 | 28 x 144<br>42 x 120 | 1.35 |
| 0.016 to 0.013, inclusive | 36 x 120<br>28 x 144 | 1.35 |

9. **Samples from Galvanizing Bath.**—No rerolling of sheets after leaving the galvanizing bath will be permitted, except for the purpose of straightening. The galvanizing material must show 98 per cent pure zinc, determined from a sample taken at random by a Government inspector from the upper half of the galvanizing bath. These samples may be taken at any time, provided the manufacturer agrees to have the sample represent the galvanizing for the order; otherwise, when the inspector has been unable to secure a sample of the bath used for the order, the purity of the bath may be established by a Government laboratory from a sample of galvanized sheet taken at random from the order.

10. **Determination of Amount of Zinc Coating.**—The determination of the amount of coating per square foot to be obtained by establishing the practice of the firm at convenient intervals, by weighing plates, as follows: First, weight in bulk of selected plates in the black, after pickling. Secondly, weight of the same selected plates after galvanizing. If this course cannot be pursued, the following method may be used: A selected sample from a galvanized sheet for the order, of two square feet of surface, will be sent to a Government laboratory at the expense of the manufacturer, where determination will be made of the amount of zinc coating per square foot.

## CORRUGATED GALVANIZED SHEET STEEL

### NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **General Quality.**—Corrugated sheet steel to be of a good grade of steel. Sheets to be thoroughly and uniformly galvanized and of a bright appearance; to be free from ragged edges, deep pits, or other defects. Gross weight, including steel straps for bundling, will be paid for. Weight of flat plates after galvanizing to conform to table following, with a tolerance of 5 per cent either way, provided the weight of coating is not reduced.

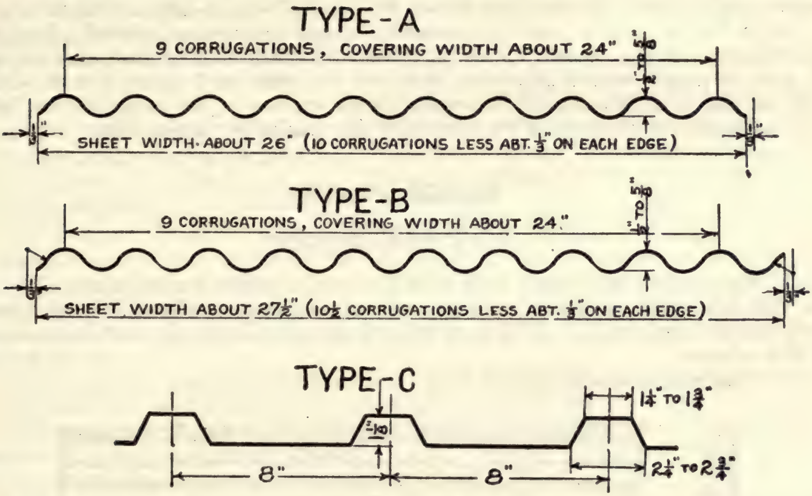
3. **Types of Corrugation.**—Corrugations will be of three types, A, B, or C, as required, in accordance with sketch incorporated in and forming a part of these specifications. Corrugations shall be approximately parallel to each other and to edges of sheet, and ends of sheet shall be approximately square. Requisitions must state type of corrugation required.

(a) For type A, width of sheet shall be sufficient to allow 9 full corrugations, covering width of 24 inches, finishing both edges down, as shown on sketch.

(b) For type B, width of sheets shall be sufficient to allow 9½ corrugations, covering width of 24 inches, finished one edge up and one edge down, as shown on sketch.

(c) For types A and B, depth of corrugations to be from ½ to ⅝ inch, inclusive, pitch center to center of corrugations being between 2½ and 2$\frac{11}{16}$ inches.

(d) For type C, the width stated should be in multiples of 8 inches, measured between




the centers of the outside corrugations. This type is to be used only where absolutely necessary.

4. **Sizes and Variations Allowed.**—All sheets to be cut full to length specified and not to exceed this length by more than ¾ inch.

5. **Data for Preparing Requisition.**—Sheets should be specified by type, length, and weight per square foot of flat galvanized plate, as given in the second column of the following table.

Standard lengths are 5, 6, 7, 8, 9, and 10 feet. Maximum length 12 feet.

The third column of the following table gives approximate weights per square foot of corrugated galvanized sheets, types A and B corresponding to the weights of flat sheets noted:

| United States Gauge No. | Weight per Square Foot, Pounds | | Minimum Zinc Coating per Square Foot, Ounces | United States Gauge No. | Weight per Square Foot, Pounds | | Minimum Zinc Coating per Square Foot, Ounces |
|---|---|---|---|---|---|---|---|
| | Flat, Galvanized | Corrugated, Galvanized | | | Flat, Galvanized | Corrugated, Galvanized | |
| 12 | 4.531 | 4.88 | 1.65 | 23 | 1.281 | 1.38 | 1.50 |
| 14 | 3.281 | 3.54 | 1.65 | 24 | 1.156 | 1.24 | 1.50 |
| 16 | 2.656 | 2.86 | 1.65 | 25 | 1.031 | 1.11 | 1.40 |
| 18 | 2.156 | 2.32 | 1.65 | 26 | .906 | .98 | 1.40 |
| 20 | 1.656 | 1.78 | 1.65 | 27 | .844 | .91 | 1.35 |
| 21 | 1.531 | 1.65 | 1.50 | 28 | .781 | .85 | 1.35 |
| 22 | 1.406 | 1.51 | 1.50 | .. | ..... | .... | .... |

6. **Samples from Galvanizing Bath.**—The galvanizing material must show 98 per cent pure zinc, determined from a sample taken at random by a Government inspector from the upper half of the galvanizing bath. These samples may be taken at any time, provided the manufacturer agrees to have the sample represent the galvanizing for the order; otherwise, when the inspector has been unable to secure a sample of the

bath used for the order, the purity of the bath may be established by a Government laboratory from a sample of galvanized sheet taken at random from the order.

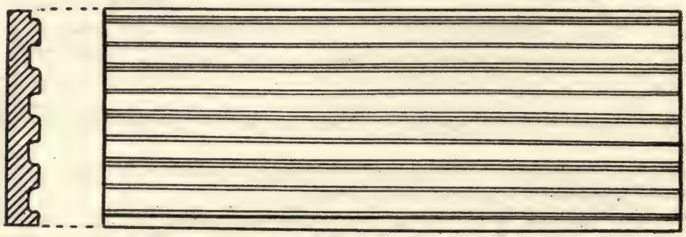
7. **Determination of the Amount of Zinc Coating.**—The determination of the amount of coating per square foot to be obtained by establishing the practice of the firm at convenient intervals, by weighing plates, as follows: First, weight in bulk of selected plates in the black, after pickling. Secondly, weight of the same selected plates after galvanizing. If this course cannot be pursued the following method may be used: A selected sample from a galvanized sheet for the order, or 2 square feet of surface, will be sent to a Government laboratory at the expense of the manufacturer, where determination will be made of the amount of zinc coating per square foot.

## FLOOR PLATES

### NAVY DEPARTMENT

1. Floor plates to be made from steel plates of domestic manufacture. They will be free from surface defects and conform to dimensions ordered. Unless ordered with planed edges, plates will be shop sheared, and a variation of $\frac{1}{8}$ inch in dimensions will be allowed.

2. They will be of ribbed pattern.



3. Ribs will be symmetrical, well defined, approximately flat tops, and the axes of patterns shall be parallel with longest dimensions. The ribs shall cover approximately half the surface.

4. The under side of the plates shall be flat and reasonably free from marks of rolls.

TABLE V

| Thickness at Bottom of Pattern: Minimum | Height of Rib | Weight: Maximum per Square Foot | Thickness at Bottom of Pattern: Minimum | Height of Rib | Weight: Maximum per Square Foot |
|---|---|---|---|---|---|
| *Inch* | *Inch* | *Pounds* | *Inch* | *Inch* | *Pounds* |
| $\frac{1}{8}$ | $\frac{3}{32}$ | 9 | $\frac{3}{8}$ | $\frac{1}{10}$ | $17\frac{3}{4}$ |
| $\frac{3}{16}$ | $\frac{3}{32}$ | $9\frac{3}{4}$ | $\frac{7}{16}$ | $\frac{1}{10}$ | $20\frac{1}{4}$ |
| $\frac{1}{4}$ | $\frac{1}{8}$ | $12\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{1}{10}$ | $22\frac{3}{4}$ |
| $\frac{5}{16}$ | $\frac{1}{8}$ | 15 | .. | .. | ... |

6. Plates exceeding weight in table by not more than 5 per cent may be accepted, but excess weight will not be paid for. A minus variation in height of rib will be allowed as follows:

Plates up to 36 inches wide.............................. 0.01 inch.
Plates 36 inches wide and over........................ 0.03 inch.
No upper limit is placed on the height.

7. Inspection will be made at place of manufacture.

# TERNEPLATE ROOFING TIN

## NAVY DEPARTMENT

All roofing tin to be made of best quality soft open-hearth steel as a basis, plates resquared, 112 sheets to the box, unless otherwise specified.

| | IC 14 by 20 Inches | IC 28 by 20 Inches | IX 14 by 20 Inches | IX 28 by 20 Inches |
|---|---|---|---|---|
| | *Pounds* | *Pounds* | *Pounds* | *Pounds* |
| Black plate from which made to weigh per 112 sheets net in the black....... | 100 to 107 | 200 to 214 | 125 to 135 | 250 to 270 |
| Tin when finished to weigh per 112 sheets net....................... | 120 to 127 | 240 to 254 | 145 to 155 | 290 to 310 |

1. Coating on all roofing tin to be a mixture of pure new tin and pure new lead thoroughly mixed, and having a proportion of not less than 20 per cent of tin and the remainder lead; coating to be thoroughly amalgamated with the black plate by the palm-oil process.

2. This coating must be applied so that the sheets be evenly and equally coated on both sides and the coating distributed equally over each sheet.

3. After the plate has been cleansed in a weak acid solution it is to be thoroughly washed with water, after which nothing is to be brought in contact with the black plate but pure palm oil, pure new tin, and pure new lead.

4. Every sheet so coated must be free from all defects, blisters, bad edges and corners, and bare or imperfectly coated spots.

Each sheet to be stamped with the brand, thickness of the plate, and name of the manufacturer.

5. The weight of coating in pounds per 112 sheets of 20 inches by 28 inches net shall not be less than 40 pounds.

6. **Terneplate (Roofing Tin) with Charcoal-Iron Base.**—In case a plate with a charcoal-iron base is specified, the foregoing specifications shall apply as regards weights of coatings and the process of manufacture.

The base or black plate shall be rolled and made from absolutely genuine charcoal iron, and no steel in the form of scrap or otherwise, or any other foreign matter, shall enter into the manufacture of the base or black plate.

7. An affidavit to the above must be furnished by the contractor, which affidavit must accompany the delivery of the roofing tin.

8. **Tinned Plate (Bright Tin).**—All tin to be made of best quality soft open-hearth steel as a basis, 112 sheets to the box, unless otherwise specified.

| | IC 14 by 20 Inches | IX 14 by 20 Inches | IXX 14 by 20 Inches | IXXXX 14 by 20 Inches |
|---|---|---|---|---|
| | *Pounds* | *Pounds* | *Pounds* | *Pounds* |
| Black plate from which made to weigh per 112 sheets net in the black....... | 102 to 107 | 129 to 135 | 148 to 156 | 187 to 197 |
| Tin when finished to weigh per 112 sheets net....................... | 107 to 112 | 134 to 140 | 153 to 161 | 192 to 202 |

9. The coating shall weigh not less than 5 pounds per 112 sheets of 14 by 20 inch size.

10. The tin is to be of the best quality of commercially pure pig tin. If other size sheets are required the same proportions of black plate and tin should be observed.

11. The coating is to be thoroughly amalgamated with the black plate. This coating must be applied so that the sheets be evenly and equally coated on both sides and the coating distributed equally over each sheet. Every sheet so coated must be free from all defects, blisters, bad edges, and corners, and bare or imperfectly coated spots.

## Weight of Rectangular Steel Plates per Lineal Foot

Reduction factor: 1 cubic inch of steel = 0.283333 pound

| Thickness, in Sixteenths of an Inch | Width, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| | Area, in Square Feet | | | | | | | |
| | 1.000 | 1.083 | 1.167 | 1.250 | 1.333 | 1.417 | 1.500 | 1.583 |
| | Weight, in Pounds | | | | | | | |
| $\frac{1}{16}$ | 2.55 | 2.76 | 2.98 | 3.19 | 3.40 | 3.61 | 3.83 | 4.04 |
| $\frac{1}{8}$ | 5.10 | 5.53 | 5.95 | 6.38 | 6.80 | 7.23 | 7.65 | 8.08 |
| $\frac{3}{16}$ | 7.65 | 8.29 | 8.93 | 9.56 | 10.20 | 10.84 | 11.48 | 12.11 |
| $\frac{1}{4}$ | 10.20 | 11.05 | 11.90 | 12.75 | 13.60 | 14.45 | 15.30 | 16.15 |
| $\frac{5}{16}$ | 12.75 | 13.81 | 14.88 | 15.94 | 17.00 | 18.06 | 19.13 | 20.19 |
| $\frac{3}{8}$ | 15.30 | 16.58 | 17.85 | 19.13 | 20.40 | 21.68 | 22.95 | 24.23 |
| $\frac{7}{16}$ | 17.85 | 19.34 | 20.83 | 22.31 | 23.80 | 25.29 | 26.78 | 28.26 |
| $\frac{1}{2}$ | 20.40 | 22.10 | 23.80 | 25.50 | 27.20 | 28.90 | 30.60 | 32.30 |
| $\frac{9}{16}$ | 22.95 | 24.86 | 26.78 | 28.69 | 30.60 | 32.51 | 34.43 | 36.34 |
| $\frac{5}{8}$ | 25.50 | 27.63 | 29.75 | 31.88 | 34.00 | 36.13 | 38.25 | 40.38 |
| $\frac{11}{16}$ | 28.05 | 30.39 | 32.73 | 35.06 | 37.40 | 39.74 | 42.08 | 44.41 |
| $\frac{3}{4}$ | 30.60 | 33.15 | 35.70 | 38.25 | 40.80 | 43.35 | 45.90 | 48.45 |
| $\frac{13}{16}$ | 33.15 | 35.91 | 38.86 | 41.44 | 44.20 | 46.96 | 49.73 | 52.49 |
| $\frac{7}{8}$ | 35.70 | 38.68 | 41.65 | 44.63 | 47.60 | 50.58 | 53.55 | 56.53 |
| $\frac{15}{16}$ | 38.25 | 41.44 | 44.63 | 47.81 | 51.00 | 54.19 | 57.38 | 60.56 |
| 1 | 40.80 | 44.20 | 47.60 | 51.00 | 54.40 | 57.80 | 61.20 | 64.60 |
| $1\frac{1}{16}$ | 43.35 | 46.96 | 50.58 | 54.19 | 57.80 | 61.41 | 65.03 | 68.64 |
| $1\frac{1}{8}$ | 45.90 | 49.73 | 53.55 | 57.38 | 61.20 | 65.03 | 68.85 | 72.68 |
| $1\frac{3}{16}$ | 48.45 | 52.49 | 56.53 | 60.56 | 64.60 | 68.64 | 72.68 | 76.71 |
| $1\frac{1}{4}$ | 51.00 | 55.25 | 59.50 | 63.75 | 68.00 | 72.25 | 76.50 | 80.75 |
| $1\frac{5}{16}$ | 53.55 | 58.01 | 62.48 | 66.94 | 71.40 | 75.86 | 80.33 | 84.79 |
| $1\frac{3}{8}$ | 56.10 | 60.78 | 65.45 | 70.13 | 74.80 | 79.48 | 84.15 | 88.83 |
| $1\frac{7}{16}$ | 58.65 | 63.54 | 68.43 | 73.31 | 78.20 | 83.09 | 87.98 | 92.86 |
| $1\frac{1}{2}$ | 61.20 | 66.30 | 71.40 | 76.50 | 81.60 | 86.70 | 91.80 | 96.90 |
| $1\frac{9}{16}$ | 63.75 | 69.06 | 74.38 | 79.69 | 85.00 | 90.31 | 95.63 | 100.94 |
| $1\frac{5}{8}$ | 66.30 | 71.83 | 77.35 | 82.88 | 88.40 | 93.93 | 99.45 | 104.98 |
| $1\frac{11}{16}$ | 68.85 | 74.59 | 80.33 | 86.06 | 91.80 | 97.54 | 103.28 | 109.01 |
| $1\frac{3}{4}$ | 71.40 | 77.35 | 83.30 | 89.25 | 95.20 | 101.15 | 107.10 | 113.05 |
| $1\frac{13}{16}$ | 73.95 | 80.11 | 86.28 | 92.44 | 98.60 | 104.76 | 110.93 | 117.09 |
| $1\frac{7}{8}$ | 76.50 | 82.88 | 89.25 | 95.63 | 102.00 | 108.38 | 114.75 | 121.13 |
| $1\frac{15}{16}$ | 79.05 | 85.64 | 92.23 | 98.81 | 105.40 | 111.99 | 118.58 | 125.16 |
| 2 | 81.60 | 88.40 | 95.20 | 102.00 | 108.80 | 115.60 | 122.40 | 129.20 |

WEIGHT OF RECTANGULAR STEEL PLATES PER LINEAL FOOT—(*Cont.*)

| Thickness, in Sixteenths of an Inch | Width, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| | Area, in Square Feet | | | | | | | |
| | 1.667 | 1.750 | 1.833 | 1.917 | 2.000 | 2.083 | 2.167 | 2.250 |
| | Weight, in Pounds | | | | | | | |
| $\frac{1}{16}$ | 4.25 | 4.46 | 4.58 | 4.89 | 5.10 | 5.31 | 5.53 | 5.74 |
| $\frac{1}{8}$ | 8.50 | 8.93 | 9.35 | 9.78 | 10.20 | 10.63 | 11.05 | 11.48 |
| $\frac{3}{16}$ | 12.75 | 13.39 | 14.03 | 14.66 | 15.30 | 15.94 | 16.58 | 17.21 |
| $\frac{1}{4}$ | 17.00 | 17.85 | 18.70 | 19.55 | 20.40 | 21.25 | 22.10 | 22.95 |
| $\frac{5}{16}$ | 21.25 | 22.31 | 23.38 | 24.44 | 25.50 | 26.56 | 27.63 | 28.69 |
| $\frac{3}{8}$ | 25.50 | 26.78 | 28.05 | 29.33 | 30.60 | 31.88 | 33.15 | 34.43 |
| $\frac{7}{16}$ | 29.75 | 31.24 | 32.73 | 34.21 | 35.70 | 37.19 | 38.68 | 40.16 |
| $\frac{1}{2}$ | 34.00 | 35.70 | 37.40 | 39.10 | 40.80 | 42.50 | 44.20 | 45.90 |
| $\frac{9}{16}$ | 38.25 | 40.16 | 42.08 | 43.99 | 45.90 | 47.81 | 49.73 | 51.64 |
| $\frac{5}{8}$ | 42.50 | 44.63 | 46.75 | 48.88 | 51.00 | 53.13 | 55.25 | 57.38 |
| $\frac{11}{16}$ | 46.75 | 49.09 | 51.43 | 53.76 | 56.10 | 58.44 | 60.78 | 63.11 |
| $\frac{3}{4}$ | 51.00 | 53.55 | 56.10 | 58.65 | 61.20 | 63.75 | 66.30 | 68.85 |
| $\frac{13}{16}$ | 55.25 | 58.01 | 60.78 | 63.54 | 66.30 | 69.06 | 71.83 | 74.59 |
| $\frac{7}{8}$ | 59.50 | 62.48 | 65.45 | 68.43 | 71.40 | 74.38 | 77.35 | 80.33 |
| $\frac{15}{16}$ | 63.75 | 66.94 | 70.13 | 73.31 | 76.50 | 79.69 | 82.88 | 86.06 |
| 1 | 68.00 | 71.40 | 74.80 | 78.20 | 81.60 | 85.00 | 88.40 | 91.80 |
| $1\frac{1}{16}$ | 72.25 | 75.86 | 79.48 | 83.09 | 86.70 | 90.31 | 93.93 | 97.54 |
| $1\frac{1}{8}$ | 76.50 | 80.33 | 84.15 | 87.98 | 91.80 | 95.63 | 99.45 | 103.28 |
| $1\frac{3}{16}$ | 80.75 | 84.79 | 88.83 | 92.86 | 96.90 | 100.94 | 104.98 | 109.01 |
| $1\frac{1}{4}$ | 85.00 | 89.25 | 93.50 | 97.75 | 102.00 | 106.25 | 110.50 | 114.75 |
| $1\frac{5}{16}$ | 89.25 | 93.71 | 98.18 | 102.64 | 107.10 | 111.56 | 116.03 | 120.49 |
| $1\frac{3}{8}$ | 93.50 | 98.18 | 102.85 | 107.53 | 112.20 | 116.88 | 121.55 | 126.23 |
| $1\frac{7}{16}$ | 97.75 | 102.64 | 107.53 | 112.41 | 117.30 | 122.19 | 127.08 | 131.96 |
| $1\frac{1}{2}$ | 102.00 | 107.10 | 112.20 | 117.30 | 122.40 | 127.50 | 132.60 | 137.70 |
| $1\frac{9}{16}$ | 106.25 | 111.56 | 116.88 | 122.19 | 127.50 | 132.81 | 138.13 | 143.44 |
| $1\frac{5}{8}$ | 110.50 | 116.03 | 121.55 | 127.08 | 132.60 | 138.13 | 143.65 | 149.18 |
| $1\frac{11}{16}$ | 114.75 | 120.49 | 126.23 | 131.96 | 137.70 | 143.44 | 149.18 | 154.91 |
| $1\frac{3}{4}$ | 119.00 | 124.95 | 130.90 | 136.85 | 142.80 | 148.75 | 154.70 | 160.65 |
| $1\frac{13}{16}$ | 123.25 | 129.41 | 135.58 | 141.74 | 147.90 | 154.06 | 160.23 | 166.39 |
| $1\frac{7}{8}$ | 127.50 | 133.88 | 140.25 | 146.63 | 153.00 | 159.38 | 165.75 | 172.13 |
| $1\frac{15}{16}$ | 131.75 | 138.34 | 144.93 | 151.51 | 158.10 | 164.69 | 171.28 | 177.86 |
| 2 | 136.00 | 142.80 | 149.60 | 156.40 | 163.20 | 170.00 | 176.80 | 183.60 |

WEIGHT OF RECTANGULAR STEEL PLATES PER LINEAL FOOT—(*Cont.*)

| Thickness, in Sixteenths of an Inch | Width, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 |
| | Area, in Square Feet | | | | | | | |
| | 2.333 | 2.417 | 2.500 | 2.583 | 2.667 | 2.750 | 2.833 | 2.917 |
| | Weight, in Pounds | | | | | | | |
| $\frac{1}{16}$ | 5.95 | 6.16 | 6.38 | 6.59 | 6.80 | 7.01 | 7.23 | 7.44 |
| $\frac{1}{8}$ | 11.90 | 12.33 | 12.75 | 13.18 | 13.60 | 14.03 | 14.45 | 14.88 |
| $\frac{3}{16}$ | 17.85 | 18.49 | 19.13 | 19.76 | 20.40 | 21.04 | 21.68 | 22.31 |
| $\frac{1}{4}$ | 23.80 | 24.65 | 25.50 | 26.35 | 27.20 | 28.05 | 28.90 | 29.75 |
| $\frac{5}{16}$ | 29.75 | 30.81 | 31.88 | 32.94 | 34.00 | 35.06 | 36.13 | 37.19 |
| $\frac{3}{8}$ | 35.70 | 36.98 | 38.25 | 39.53 | 40.80 | 42.08 | 43.35 | 44.63 |
| $\frac{7}{16}$ | 41.65 | 43.14 | 44.63 | 46.11 | 47.60 | 49.09 | 50.58 | 52.06 |
| $\frac{1}{2}$ | 47.60 | 49.30 | 51.00 | 52.70 | 54.40 | 56.10 | 57.80 | 59.50 |
| $\frac{9}{16}$ | 53.55 | 55.46 | 57.38 | 59.29 | 61.20 | 63.11 | 65.03 | 66.94 |
| $\frac{5}{8}$ | 59.50 | 61.63 | 63.75 | 65.88 | 68.00 | 70.13 | 72.25 | 74.38 |
| $\frac{11}{16}$ | 65.45 | 67.79 | 70.13 | 72.46 | 74.80 | 77.14 | 79.48 | 81.81 |
| $\frac{3}{4}$ | 71.40 | 73.95 | 76.50 | 79.05 | 81.60 | 84.15 | 86.70 | 89.25 |
| $\frac{13}{16}$ | 77.35 | 80.11 | 82.88 | 85.64 | 88.40 | 91.16 | 93.93 | 96.69 |
| $\frac{7}{8}$ | 83.30 | 86.28 | 89.25 | 92.23 | 95.20 | 98.18 | 101.15 | 104.13 |
| $\frac{15}{16}$ | 89.25 | 92.44 | 95.63 | 98.81 | 102.00 | 105.19 | 108.38 | 111.56 |
| 1 | 95.20 | 98.60 | 102.00 | 105.40 | 108.80 | 112.20 | 115.60 | 119.00 |
| $1\frac{1}{16}$ | 101.15 | 104.76 | 108.38 | 111.99 | 115.60 | 119.21 | 122.83 | 126.44 |
| $1\frac{1}{8}$ | 107.10 | 110.93 | 114.75 | 118.58 | 122.40 | 126.23 | 130.05 | 133.88 |
| $1\frac{3}{16}$ | 113.05 | 117.09 | 121.13 | 125.16 | 129.20 | 133.24 | 137.28 | 141.31 |
| $1\frac{1}{4}$ | 119.00 | 123.25 | 127.50 | 131.75 | 136.00 | 140.25 | 144.50 | 148.75 |
| $1\frac{5}{16}$ | 124.95 | 129.41 | 133.88 | 138.34 | 142.80 | 147.26 | 151.73 | 156.19 |
| $1\frac{3}{8}$ | 130.90 | 135.58 | 140.25 | 144.93 | 149.60 | 154.28 | 158.95 | 163.63 |
| $1\frac{7}{16}$ | 136.85 | 141.74 | 146.63 | 151.51 | 156.40 | 161.29 | 166.18 | 171.06 |
| $1\frac{1}{2}$ | 142.80 | 147.90 | 153.00 | 158.10 | 163.20 | 168.30 | 173.40 | 178.50 |
| $1\frac{9}{16}$ | 148.75 | 154.06 | 159.38 | 164.69 | 170.00 | 175.31 | 180.63 | 185.94 |
| $1\frac{5}{8}$ | 154.70 | 160.23 | 165.75 | 171.28 | 176.80 | 182.33 | 187.85 | 193.38 |
| $1\frac{11}{16}$ | 160.65 | 166.39 | 172.13 | 177.86 | 183.60 | 189.34 | 195.08 | 200.81 |
| $1\frac{3}{4}$ | 166.60 | 172.55 | 178.50 | 184.45 | 190.40 | 196.35 | 202.30 | 208.25 |
| $1\frac{13}{16}$ | 172.55 | 178.71 | 184.88 | 191.04 | 197.20 | 203.36 | 209.53 | 215.69 |
| $1\frac{7}{8}$ | 178.50 | 184.88 | 191.25 | 197.63 | 204.00 | 210.38 | 216.75 | 223.13 |
| $1\frac{15}{16}$ | 184.45 | 191.04 | 197.63 | 204.21 | 210.80 | 217.39 | 223.98 | 230.56 |
| 2 | 190.40 | 197.20 | 204.00 | 210.80 | 217.60 | 224.40 | 231.20 | 238.00 |

WEIGHT OF RECTANGULAR STEEL PLATES PER LINEAL FOOT—(*Cont.*)

| Thickness, in Sixteenths of an Inch | Width, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 |
| | Area, in Square Feet | | | | | | | |
| | 3.000 | 3.083 | 3.167 | 3.250 | 3.333 | 3.417 | 3.500 | 3.583 |
| | Weight, in Pounds | | | | | | | |
| $\frac{1}{16}$ | 7.65 | 7.86 | 8.08 | 8.29 | 8.50 | 8.71 | 8.93 | 9.14 |
| $\frac{1}{8}$ | 15.30 | 15.73 | 16.15 | 16.58 | 17.00 | 17.43 | 17.85 | 18.28 |
| $\frac{3}{16}$ | 22.95 | 23.59 | 24.23 | 24.86 | 25.50 | 26.14 | 26.78 | 27.41 |
| $\frac{1}{4}$ | 30.60 | 31.45 | 32.30 | 33.15 | 34.00 | 34.85 | 35.70 | 36.55 |
| $\frac{5}{16}$ | 38.25 | 39.31 | 40.38 | 41.44 | 42.50 | 43.56 | 44.63 | 45.69 |
| $\frac{3}{8}$ | 45.90 | 47.18 | 48.45 | 49.73 | 51.00 | 52.28 | 53.55 | 54.83 |
| $\frac{7}{16}$ | 53.55 | 55.04 | 56.33 | 58.01 | 59.50 | 60.99 | 62.48 | 63.96 |
| $\frac{1}{2}$ | 61.20 | 62.90 | 64.60 | 66.30 | 68.00 | 69.70 | 71.40 | 73.10 |
| $\frac{9}{16}$ | 68.85 | 70.76 | 72.68 | 74.59 | 76.50 | 78.41 | 80.33 | 82.24 |
| $\frac{5}{8}$ | 76.50 | 78.63 | 80.75 | 82.88 | 85.00 | 87.13 | 89.25 | 91.38 |
| $\frac{11}{16}$ | 84.15 | 86.49 | 88.83 | 91.16 | 93.50 | 95.84 | 98.18 | 100.51 |
| $\frac{3}{4}$ | 91.80 | 94.35 | 96.90 | 99.45 | 102.00 | 104.55 | 107.10 | 109.65 |
| $\frac{13}{16}$ | 99.45 | 102.21 | 104.98 | 107.74 | 110.50 | 113.26 | 116.03 | 118.79 |
| $\frac{7}{8}$ | 107.10 | 110.08 | 113.05 | 116.03 | 119.00 | 121.98 | 124.95 | 127.93 |
| $\frac{15}{16}$ | 114.75 | 117.94 | 121.13 | 124.31 | 127.50 | 130.69 | 133.88 | 137.06 |
| 1 | 122.40 | 125.80 | 129.20 | 132.60 | 136.00 | 139.40 | 142.80 | 146.20 |
| $1\frac{1}{16}$ | 130.05 | 133.66 | 137.28 | 140.89 | 144.50 | 148.11 | 151.73 | 155.34 |
| $1\frac{1}{8}$ | 137.70 | 141.53 | 145.35 | 149.18 | 153.00 | 156.83 | 160.65 | 164.48 |
| $1\frac{3}{16}$ | 145.35 | 149.39 | 153.43 | 157.46 | 161.50 | 165.54 | 169.58 | 173.61 |
| $1\frac{1}{4}$ | 153.00 | 157.25 | 161.50 | 165.75 | 170.00 | 174.25 | 178.50 | 182.75 |
| $1\frac{5}{16}$ | 160.65 | 165.11 | 169.58 | 174.04 | 178.50 | 182.96 | 187.43 | 191.89 |
| $1\frac{3}{8}$ | 168.30 | 172.98 | 177.65 | 182.33 | 187.00 | 191.68 | 196.35 | 201.03 |
| $1\frac{7}{16}$ | 175.95 | 180.84 | 185.73 | 190.61 | 195.50 | 200.39 | 205.28 | 210.16 |
| $1\frac{1}{2}$ | 183.60 | 188.70 | 193.80 | 198.90 | 204.00 | 209.10 | 214.20 | 219.30 |
| $1\frac{9}{16}$ | 191.25 | 196.56 | 201.88 | 207.19 | 212.50 | 217.81 | 223.13 | 228.44 |
| $1\frac{5}{8}$ | 198.90 | 204.43 | 209.95 | 215.48 | 221.00 | 226.53 | 232.05 | 237.58 |
| $1\frac{11}{16}$ | 206.55 | 212.29 | 218.03 | 223.76 | 229.50 | 235.24 | 240.98 | 246.71 |
| $1\frac{3}{4}$ | 214.20 | 220.15 | 226.10 | 232.05 | 238.00 | 243.95 | 249.90 | 255.85 |
| $1\frac{13}{16}$ | 221.85 | 228.01 | 234.18 | 240.34 | 246.50 | 252.66 | 258.83 | 264.99 |
| $1\frac{7}{8}$ | 229.50 | 235.88 | 242.25 | 248.63 | 255.00 | 261.38 | 267.75 | 274.13 |
| $1\frac{15}{16}$ | 237.15 | 243.74 | 250.33 | 256.91 | 263.50 | 270.09 | 276.68 | 283.26 |
| 2 | 244.80 | 251.60 | 258.40 | 265.20 | 272.00 | 278.80 | 285.60 | 292.40 |

WEIGHT OF RECTANGULAR STEEL PLATES PER LINEAL FOOT—(*Cont.*)

| Thickness, in Sixteenths of an Inch | Width, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 |
| | Area, in Square Feet | | | | | | | |
| | 3.667 | 3.750 | 3.833 | 3.917 | 4.000 | 4.083 | 4.167 | 4.250 |
| | Weight, in Pounds | | | | | | | |
| $\frac{1}{16}$ | 9.35 | 9.56 | 9.78 | 9.99 | 10.20 | 10.41 | 10.63 | 10.84 |
| $\frac{1}{8}$ | 18.70 | 19.13 | 19.55 | 19.98 | 20.40 | 20.83 | 21.25 | 21.68 |
| $\frac{3}{16}$ | 28.05 | 28.69 | 29.33 | 29.96 | 30.60 | 31.24 | 31.88 | 32.51 |
| $\frac{1}{4}$ | 37.40 | 38.25 | 39.10 | 39.95 | 40.80 | 41.65 | 42.50 | 43.35 |
| $\frac{5}{16}$ | 46.75 | 47.81 | 48.88 | 49.94 | 51.00 | 52.06 | 53.13 | 54.19 |
| $\frac{3}{8}$ | 56.10 | 57.38 | 58.65 | 59.93 | 61.20 | 62.48 | 73.75 | 65.03 |
| $\frac{7}{16}$ | 65.45 | 66.94 | 68.43 | 69.91 | 71.40 | 72.89 | 74.38 | 75.86 |
| $\frac{1}{2}$ | 74.80 | 76.50 | 78.20 | 79.90 | 81.60 | 83.30 | 85.00 | 86.70 |
| $\frac{9}{16}$ | 84.15 | 86.06 | 87.98 | 89.89 | 91.80 | 93.71 | 95.63 | 97.54 |
| $\frac{5}{8}$ | 93.50 | 95.63 | 97.75 | 99.88 | 102.00 | 104.13 | 106.25 | 108.38 |
| $\frac{11}{16}$ | 102.85 | 105.19 | 107.53 | 109.86 | 112.20 | 114.54 | 116.88 | 119.21 |
| $\frac{3}{4}$ | 112.20 | 114.75 | 117.30 | 119.85 | 122.40 | 124.95 | 127.50 | 130.05 |
| $\frac{13}{16}$ | 121.55 | 124.31 | 127.08 | 129.84 | 132.60 | 135.36 | 138.13 | 140.89 |
| $\frac{7}{8}$ | 130.90 | 133.88 | 136.85 | 139.83 | 142.80 | 145.78 | 148.75 | 151.73 |
| $\frac{15}{16}$ | 140.25 | 143.44 | 146.63 | 149.81 | 153.00 | 156.19 | 159.38 | 162.56 |
| 1 | 149.60 | 153.00 | 156.40 | 159.80 | 163.20 | 166.60 | 170.00 | 173.40 |
| $1\frac{1}{16}$ | 158.95 | 162.56 | 166.18 | 169.79 | 173.40 | 177.01 | 180.63 | 184.24 |
| $1\frac{1}{8}$ | 168.30 | 172.13 | 175.95 | 179.78 | 183.60 | 187.43 | 191.25 | 195.08 |
| $1\frac{3}{16}$ | 177.65 | 181.69 | 185.72 | 189.76 | 193.80 | 197.84 | 201.88 | 205.91 |
| $1\frac{1}{4}$ | 187.00 | 191.25 | 195.50 | 199.75 | 204.00 | 208.25 | 212.50 | 216.75 |
| $1\frac{5}{16}$ | 196.35 | 200.81 | 205.28 | 209.74 | 214.20 | 218.66 | 223.13 | 227.59 |
| $1\frac{3}{8}$ | 205.70 | 210.38 | 215.05 | 219.73 | 224.40 | 229.08 | 233.75 | 238.43 |
| $1\frac{7}{16}$ | 215.05 | 219.94 | 224.83 | 229.71 | 234.60 | 239.49 | 244.38 | 249.26 |
| $1\frac{1}{2}$ | 224.40 | 229.50 | 234.60 | 239.70 | 244.80 | 249.90 | 255.00 | 260.10 |
| $1\frac{9}{16}$ | 233.75 | 239.06 | 244.38 | 249.69 | 255.00 | 260.31 | 265.63 | 270.94 |
| $1\frac{5}{8}$ | 243.10 | 248.63 | 254.15 | 259.68 | 265.20 | 270.73 | 276.25 | 281.78 |
| $1\frac{11}{16}$ | 252.45 | 258.19 | 263.93 | 269.66 | 275.40 | 281.14 | 286.88 | 292.61 |
| $1\frac{3}{4}$ | 261.80 | 267.75 | 273.70 | 279.65 | 285.60 | 291.55 | 297.50 | 303.45 |
| $1\frac{13}{16}$ | 271.15 | 277.31 | 283.48 | 289.64 | 295.80 | 301.96 | 308.13 | 314.29 |
| $1\frac{7}{8}$ | 280.50 | 286.88 | 293.25 | 299.63 | 306.00 | 312.38 | 318.75 | 325.13 |
| $1\frac{15}{16}$ | 289.85 | 296.44 | 303.03 | 309.61 | 316.20 | 322.79 | 329.38 | 335.96 |
| 2 | 299.20 | 306.00 | 312.80 | 319.60 | 326.40 | 333.20 | 340.00 | 346.80 |

### Weight of Rectangular Steel Plates per Lineal Foot—(*Cont.*)

| Thickness, in Sixteenths of an Inch | Width, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 |
| | Area, in Square Feet | | | | | | | |
| | 4.333 | 4.417 | 4.500 | 4.583 | 4.667 | 4.750 | 4.833 | 4.917 |
| | Weight, in Pounds | | | | | | | |
| $\frac{1}{16}$ | 11.05 | 11.26 | 11.48 | 11.69 | 11.90 | 12.11 | 12.33 | 12.54 |
| $\frac{1}{8}$ | 22.10 | 22.53 | 22.95 | 23.38 | 23.80 | 24.23 | 24.65 | 25.08 |
| $\frac{3}{16}$ | 33.15 | 33.79 | 34.43 | 35.06 | 35.70 | 36.34 | 36.98 | 37.61 |
| $\frac{1}{4}$ | 44.20 | 45.05 | 45.90 | 46.75 | 47.60 | 48.45 | 49.30 | 50.15 |
| $\frac{5}{16}$ | 55.25 | 56.31 | 57.38 | 58.44 | 59.50 | 60.56 | 61.63 | 62.69 |
| $\frac{3}{8}$ | 66.30 | 77.58 | 68.85 | 70.13 | 71.40 | 72.68 | 73.95 | 75.23 |
| $\frac{7}{16}$ | 77.35 | 78.84 | 80.33 | 81.81 | 83.30 | 84.79 | 86.28 | 87.76 |
| $\frac{1}{2}$ | 88.40 | 90.10 | 91.80 | 93.50 | 95.20 | 96.90 | 98.60 | 100.30 |
| $\frac{9}{16}$ | 99.45 | 101.36 | 103.28 | 105.19 | 107.10 | 109.01 | 110.93 | 112.84 |
| $\frac{5}{8}$ | 110.50 | 112.63 | 114.75 | 116.88 | 119.00 | 121.13 | 123.25 | 125.38 |
| $\frac{11}{16}$ | 121.55 | 123.89 | 126.23 | 128.56 | 130.90 | 133.24 | 135.58 | 137.91 |
| $\frac{3}{4}$ | 132.60 | 135.15 | 137.70 | 140.25 | 142.80 | 145.35 | 147.90 | 150.45 |
| $\frac{13}{16}$ | 143.65 | 146.41 | 149.18 | 151.94 | 154.70 | 157.46 | 160.23 | 162.99 |
| $\frac{7}{8}$ | 154.70 | 157.68 | 160.65 | 163.63 | 166.60 | 169.58 | 172.55 | 175.53 |
| $\frac{15}{16}$ | 165.75 | 168.94 | 172.13 | 175.31 | 178.50 | 181.69 | 184.88 | 188.06 |
| 1 | 176.80 | 180.20 | 183.60 | 187.00 | 190.40 | 193.80 | 197.20 | 200.60 |
| $1\frac{1}{16}$ | 187.85 | 191.46 | 195.08 | 198.69 | 202.30 | 205.91 | 209.53 | 213.14 |
| $1\frac{1}{8}$ | 198.90 | 202.73 | 206.55 | 210.38 | 214.20 | 218.03 | 221.85 | 225.68 |
| $1\frac{3}{16}$ | 209.95 | 213.99 | 218.03 | 222.06 | 226.10 | 230.14 | 234.18 | 238.21 |
| $1\frac{1}{4}$ | 221.00 | 225.25 | 229.50 | 233.75 | 238.00 | 242.25 | 246.50 | 250.75 |
| $1\frac{5}{16}$ | 232.05 | 236.51 | 240.98 | 245.44 | 249.90 | 254.36 | 258.83 | 263.29 |
| $1\frac{3}{8}$ | 243.10 | 247.78 | 252.45 | 257.13 | 261.80 | 266.48 | 271.15 | 275.83 |
| $1\frac{7}{16}$ | 254.15 | 259.04 | 263.93 | 268.81 | 273.70 | 278.59 | 283.48 | 288.36 |
| $1\frac{1}{2}$ | 265.20 | 270.30 | 275.40 | 280.50 | 285.60 | 290.70 | 295.80 | 300.90 |
| $1\frac{9}{16}$ | 276.25 | 281.56 | 286.88 | 292.19 | 297.50 | 302.81 | 308.13 | 313.44 |
| $1\frac{5}{8}$ | 287.30 | 292.83 | 298.35 | 303.88 | 309.40 | 314.93 | 320.45 | 325.98 |
| $1\frac{11}{16}$ | 298.35 | 304.09 | 309.83 | 315.56 | 321.30 | 327.04 | 332.78 | 338.51 |
| $1\frac{3}{4}$ | 309.40 | 315.35 | 321.30 | 327.25 | 333.20 | 339.15 | 345.10 | 351.05 |
| $1\frac{13}{16}$ | 320.45 | 326.61 | 332.78 | 338.94 | 345.10 | 351.26 | 357.43 | 363.59 |
| $1\frac{7}{8}$ | 331.50 | 337.88 | 344.25 | 350.63 | 357.00 | 363.38 | 369.75 | 376.13 |
| $1\frac{15}{16}$ | 342.55 | 349.14 | 355.73 | 362.31 | 368.90 | 375.49 | 382.08 | 388.66 |
| 2 | 353.60 | 360.40 | 367.20 | 374.00 | 380.80 | 387.60 | 394.40 | 401.20 |

WEIGHT OF RECTANGULAR STEEL PLATES PER LINEAL FOOT—(*Cont.*)

| Thickness, in Sixteenths of an Inch | Width, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 |
| | Area, in Square Feet | | | | | | | |
| | 5.000 | 5.083 | 5.167 | 5.250 | 5.333 | 5.417 | 5.500 | 5.583 |
| | Weight, in Pounds | | | | | | | |
| $\frac{1}{16}$ | 12.75 | 12.96 | 13.18 | 13.39 | 13.60 | 13.81 | 14.03 | 14.24 |
| $\frac{1}{8}$ | 25.50 | 25.93 | 26.35 | 26.78 | 27.20 | 27.63 | 28.05 | 28.48 |
| $\frac{3}{16}$ | 38.25 | 38.89 | 39.53 | 40.16 | 40.80 | 41.44 | 42.08 | 42.71 |
| $\frac{1}{4}$ | 51.00 | 51.85 | 52.70 | 53.55 | 54.40 | 55.25 | 56.10 | 56.95 |
| $\frac{5}{16}$ | 63.75 | 64.81 | 65.88 | 66.94 | 68.00 | 69.06 | 70.13 | 71.19 |
| $\frac{3}{8}$ | 76.50 | 77.78 | 79.05 | 80.33 | 81.60 | 82.88 | 84.15 | 85.43 |
| $\frac{7}{16}$ | 89.25 | 90.74 | 92.23 | 93.71 | 95.20 | 96.69 | 98.18 | 99.66 |
| $\frac{1}{2}$ | 102.00 | 103.70 | 105.40 | 107.10 | 108.80 | 110.50 | 112.20 | 113.90 |
| $\frac{9}{16}$ | 114.75 | 116.66 | 118.58 | 120.49 | 122.40 | 124.31 | 126.23 | 128.14 |
| $\frac{5}{8}$ | 127.50 | 129.63 | 131.75 | 133.88 | 136.00 | 138.13 | 140.25 | 142.38 |
| $\frac{11}{16}$ | 140.25 | 142.59 | 144.93 | 147.26 | 149.60 | 151.94 | 154.28 | 156.61 |
| $\frac{3}{4}$ | 153.00 | 155.55 | 158.10 | 160.65 | 163.20 | 165.75 | 168.30 | 170.85 |
| $\frac{13}{16}$ | 165.75 | 168.51 | 171.28 | 174.04 | 176.80 | 179.56 | 182.33 | 185.09 |
| $\frac{7}{8}$ | 178.50 | 181.48 | 184.45 | 187.43 | 190.40 | 193.38 | 196.35 | 199.33 |
| $\frac{15}{16}$ | 191.25 | 194.44 | 197.63 | 200.81 | 204.00 | 207.19 | 210.38 | 213.56 |
| 1 | 204.00 | 207.40 | 210.80 | 214.20 | 217.60 | 221.00 | 224.40 | 227.80 |
| $1\frac{1}{16}$ | 216.75 | 220.36 | 223.98 | 227.59 | 231.20 | 234.81 | 238.43 | 242.04 |
| $1\frac{1}{8}$ | 229.50 | 233.33 | 237.15 | 240.98 | 244.80 | 248.63 | 252.45 | 256.28 |
| $1\frac{3}{16}$ | 242.25 | 246.29 | 250.33 | 254.36 | 258.40 | 262.44 | 266.48 | 270.51 |
| $1\frac{1}{4}$ | 255.00 | 259.25 | 263.50 | 267.75 | 272.00 | 276.25 | 280.50 | 284.75 |
| $1\frac{5}{16}$ | 267.75 | 272.21 | 276.68 | 281.14 | 285.60 | 290.06 | 294.53 | 298.99 |
| $1\frac{3}{8}$ | 280.50 | 285.18 | 289.85 | 294.53 | 299.20 | 303.88 | 308.55 | 313.23 |
| $1\frac{7}{16}$ | 293.25 | 298.14 | 303.03 | 307.91 | 312.80 | 317.69 | 322.58 | 327.46 |
| $1\frac{1}{2}$ | 306.00 | 311.10 | 316.20 | 321.30 | 326.40 | 331.50 | 336.60 | 341.70 |
| $1\frac{9}{16}$ | 318.75 | 324.06 | 329.38 | 334.69 | 340.00 | 345.31 | 350.63 | 355.94 |
| $1\frac{5}{8}$ | 331.50 | 337.03 | 342.55 | 348.08 | 353.60 | 359.13 | 364.65 | 370.18 |
| $1\frac{11}{16}$ | 344.25 | 349.99 | 355.73 | 361.46 | 367.20 | 372.94 | 378.68 | 384.41 |
| $1\frac{3}{4}$ | 357.00 | 362.95 | 368.90 | 374.85 | 380.80 | 386.75 | 392.70 | 398.65 |
| $1\frac{13}{16}$ | 369.75 | 375.91 | 382.08 | 388.24 | 394.40 | 400.56 | 406.73 | 412.89 |
| $1\frac{7}{8}$ | 382.50 | 388.88 | 395.25 | 401.63 | 408.00 | 414.38 | 420.75 | 427.13 |
| $1\frac{15}{16}$ | 395.25 | 401.84 | 408.43 | 415.01 | 421.60 | 428.19 | 434.78 | 441.36 |
| 2 | 408.00 | 414.80 | 421.60 | 428.40 | 435.20 | 442.00 | 448.80 | 455.60 |

WEIGHT OF RECTANGULAR STEEL PLATES PER LINEAL FOOT—(*Cont.*)

| Thickness, in Sixteenths of an Inch | Width, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 |
| | Area, in Square Feet | | | | | | | |
| | 5.667 | 5.750 | 5.833 | 5.917 | 6.000 | 6.083 | 6.167 | 6.250 |
| | Weight, in Pounds | | | | | | | |
| $\frac{1}{16}$ | 14.45 | 14.66 | 14.88 | 15.09 | 15.30 | 15.51 | 15.73 | 15.94 |
| $\frac{1}{8}$ | 28.90 | 29.33 | 29.75 | 30.18 | 30.60 | 31.03 | 31.45 | 31.88 |
| $\frac{3}{16}$ | 43.35 | 43.99 | 44.63 | 45.26 | 45.90 | 46.54 | 47.18 | 47.81 |
| $\frac{1}{4}$ | 57.80 | 58.65 | 59.50 | 60.35 | 61.20 | 62.05 | 62.90 | 63.75 |
| $\frac{5}{16}$ | 72.25 | 73.31 | 74.38 | 75.44 | 76.50 | 77.56 | 78.63 | 79.69 |
| $\frac{3}{8}$ | 86.70 | 87.98 | 89.25 | 90.53 | 91.80 | 93.08 | 94.35 | 95.63 |
| $\frac{7}{16}$ | 101.15 | 102.64 | 104.13 | 105.61 | 107.10 | 108.59 | 110.08 | 111.56 |
| $\frac{1}{2}$ | 115.60 | 117.30 | 119.00 | 120.70 | 122.40 | 124.10 | 125.80 | 127.50 |
| $\frac{9}{16}$ | 130.05 | 131.96 | 133.88 | 135.79 | 137.70 | 139.61 | 141.53 | 143.44 |
| $\frac{5}{8}$ | 144.50 | 146.63 | 148.75 | 150.88 | 153.00 | 155.13 | 157.25 | 159.38 |
| $\frac{11}{16}$ | 158.95 | 161.29 | 163.63 | 165.96 | 168.30 | 170.64 | 172.98 | 175.31 |
| $\frac{3}{4}$ | 173.40 | 175.95 | 178.50 | 181.05 | 183.60 | 186.15 | 188.70 | 191.25 |
| $\frac{13}{16}$ | 187.85 | 190.61 | 193.38 | 196.14 | 198.90 | 201.66 | 204.43 | 207.19 |
| $\frac{7}{8}$ | 202.30 | 205.28 | 208.25 | 211.23 | 214.20 | 217.18 | 220.15 | 223.13 |
| $\frac{15}{16}$ | 216.75 | 219.94 | 223.13 | 226.31 | 229.50 | 232.69 | 235.88 | 239.06 |
| 1 | 231.20 | 234.60 | 238.00 | 241.40 | 244.80 | 248.20 | 251.60 | 255.00 |
| $1\frac{1}{16}$ | 245.65 | 249.26 | 252.88 | 256.49 | 260.10 | 263.71 | 267.33 | 270.94 |
| $1\frac{1}{8}$ | 260.10 | 263.93 | 267.75 | 271.58 | 275.40 | 279.23 | 283.05 | 286.88 |
| $1\frac{3}{16}$ | 274.55 | 278.59 | 282.63 | 286.66 | 290.70 | 294.74 | 298.78 | 302.81 |
| $1\frac{1}{4}$ | 289.00 | 293.25 | 297.50 | 301.75 | 306.00 | 310.25 | 314.50 | 318.75 |
| $1\frac{5}{16}$ | 303.45 | 307.91 | 312.38 | 316.84 | 321.30 | 325.76 | 330.23 | 334.69 |
| $1\frac{3}{8}$ | 317.90 | 322.58 | 327.25 | 331.93 | 336.60 | 341.28 | 345.95 | 350.63 |
| $1\frac{7}{16}$ | 332.35 | 337.24 | 342.13 | 347.01 | 351.90 | 356.79 | 361.68 | 366.56 |
| $1\frac{1}{2}$ | 346.80 | 351.90 | 357.00 | 362.10 | 367.20 | 372.30 | 377.40 | 382.50 |
| $1\frac{9}{16}$ | 361.25 | 366.56 | 371.88 | 377.19 | 382.50 | 387.81 | 393.13 | 398.44 |
| $1\frac{5}{8}$ | 375.70 | 381.23 | 386.75 | 392.28 | 397.80 | 403.33 | 408.85 | 414.38 |
| $1\frac{11}{16}$ | 390.15 | 395.89 | 401.63 | 407.36 | 413.10 | 418.84 | 424.58 | 430.31 |
| $1\frac{3}{4}$ | 404.60 | 410.55 | 416.50 | 422.45 | 428.40 | 434.35 | 440.30 | 446.25 |
| $1\frac{13}{16}$ | 419.05 | 425.21 | 431.38 | 437.54 | 443.70 | 449.86 | 456.03 | 462.19 |
| $1\frac{7}{8}$ | 433.50 | 439.88 | 446.25 | 452.63 | 459.00 | 465.38 | 471.75 | 478.13 |
| $1\frac{15}{16}$ | 447.95 | 454.54 | 461.13 | 467.71 | 474.30 | 480.89 | 487.48 | 494.06 |
| 2 | 462.40 | 469.20 | 476.00 | 482.80 | 489.60 | 496.40 | 503.20 | 510.00 |

WEIGHT OF RECTANGULAR STEEL PLATES PER LINEAL FOOT—(*Cont.*)

| Thickness, in Sixteenths of an Inch | Width, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 |
| | Area, in Square Feet | | | | | | | |
| | 6.333 | 6.417 | 6.500 | 6.583 | 6.667 | 6.750 | 6.833 | 6.917 |
| | Weight, in Pounds | | | | | | | |
| $\frac{1}{16}$ | 16.15 | 16.36 | 16.58 | 16.79 | 17.00 | 17.21 | 17.43 | 17.64 |
| $\frac{1}{8}$ | 32.30 | 32.73 | 33.15 | 33.58 | 34.00 | 34.43 | 34.85 | 35.28 |
| $\frac{3}{16}$ | 48.45 | 49.09 | 49.73 | 50.36 | 51.00 | 51.64 | 52.28 | 52.91 |
| $\frac{1}{4}$ | 64.60 | 65.45 | 66.30 | 67.15 | 68.00 | 68.85 | 69.70 | 70.55 |
| $\frac{5}{16}$ | 80.75 | 81.81 | 82.88 | 83.94 | 85.00 | 86.06 | 87.13 | 88.19 |
| $\frac{3}{8}$ | 96.90 | 98.18 | 99.45 | 100.73 | 102.00 | 103.28 | 104.55 | 105.83 |
| $\frac{7}{16}$ | 113.05 | 114.54 | 116.03 | 117.51 | 119.00 | 120.49 | 121.98 | 123.46 |
| $\frac{1}{2}$ | 129.20 | 130.90 | 132.60 | 134.30 | 136.00 | 137.70 | 139.40 | 141.10 |
| $\frac{9}{16}$ | 145.35 | 147.26 | 149.18 | 151.09 | 153.00 | 154.91 | 156.83 | 158.74 |
| $\frac{5}{8}$ | 161.50 | 163.63 | 165.75 | 167.88 | 170.00 | 172.13 | 174.25 | 176.38 |
| $\frac{11}{16}$ | 177.65 | 179.99 | 182.33 | 184.66 | 187.00 | 189.34 | 191.68 | 194.01 |
| $\frac{3}{4}$ | 193.80 | 196.35 | 198.90 | 201.45 | 204.00 | 206.55 | 209.10 | 211.65 |
| $\frac{13}{16}$ | 209.95 | 212.71 | 215.48 | 218.24 | 221.00 | 223.76 | 226.53 | 229.29 |
| $\frac{7}{8}$ | 226.10 | 229.08 | 232.05 | 235.03 | 238.00 | 240.98 | 243.95 | 246.93 |
| $\frac{15}{16}$ | 242.25 | 245.44 | 248.63 | 251.81 | 255.00 | 258.19 | 261.38 | 264.56 |
| 1 | 258.40 | 261.80 | 265.20 | 268.60 | 272.00 | 275.40 | 278.80 | 282.20 |
| $1\frac{1}{16}$ | 274.55 | 278.16 | 281.78 | 285.39 | 289.00 | 292.61 | 296.23 | 299.84 |
| $1\frac{1}{8}$ | 290.70 | 294.53 | 298.35 | 302.18 | 306.00 | 309.83 | 313.65 | 317.48 |
| $1\frac{3}{16}$ | 306.85 | 310.89 | 314.93 | 318.96 | 323.00 | 327.04 | 331.08 | 335.11 |
| $1\frac{1}{4}$ | 323.00 | 327.25 | 331.50 | 335.75 | 340.00 | 344.25 | 348.50 | 352.75 |
| $1\frac{5}{16}$ | 339.15 | 343.61 | 348.08 | 352.54 | 357.00 | 361.46 | 365.93 | 370.39 |
| $1\frac{3}{8}$ | 355.30 | 359.98 | 364.65 | 369.33 | 374.00 | 378.68 | 383.35 | 388.03 |
| $1\frac{7}{16}$ | 371.45 | 376.34 | 381.23 | 386.11 | 391.00 | 395.89 | 400.78 | 405.66 |
| $1\frac{1}{2}$ | 387.60 | 392.70 | 397.80 | 402.90 | 408.00 | 413.10 | 418.20 | 423.30 |
| $1\frac{9}{16}$ | 403.75 | 409.06 | 414.38 | 419.69 | 425.00 | 430.31 | 435.63 | 440.94 |
| $1\frac{5}{8}$ | 419.90 | 425.43 | 430.95 | 436.48 | 442.00 | 447.53 | 453.05 | 458.58 |
| $1\frac{11}{16}$ | 436.05 | 441.79 | 447.53 | 453.26 | 459.00 | 464.74 | 470.48 | 476.21 |
| $1\frac{3}{4}$ | 452.20 | 458.15 | 464.10 | 470.05 | 476.00 | 481.95 | 487.90 | 493.85 |
| $1\frac{13}{16}$ | 468.35 | 474.51 | 480.68 | 486.84 | 493.00 | 499.16 | 505.33 | 511.49 |
| $1\frac{7}{8}$ | 484.50 | 490.88 | 497.25 | 503.63 | 510.00 | 516.38 | 522.75 | 529.13 |
| $1\frac{15}{16}$ | 500.65 | 507.24 | 513.83 | 520.41 | 527.00 | 533.59 | 540.18 | 546.76 |
| 2 | 516.80 | 523.60 | 530.40 | 537.20 | 544.00 | 550.80 | 557.60 | 564.40 |

WEIGHT OF RECTANGULAR STEEL PLATES PER LINEAL FOOT—(*Cont.*)

| Thickness, in Sixteenths of an Inch | Width, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 |
| | Area, in Square Feet | | | | | | | |
| | 7.000 | 7.083 | 7.167 | 7.250 | 7.333 | 7.417 | 7.500 | 7.583 |
| | Weight, in Pounds | | | | | | | |
| $\frac{1}{16}$ | 17.85 | 18.06 | 18.28 | 18.49 | 18.70 | 18.91 | 19.13 | 19.34 |
| $\frac{1}{8}$ | 35.70 | 36.13 | 36.55 | 36.98 | 37.40 | 37.83 | 38.25 | 38.68 |
| $\frac{3}{16}$ | 53.55 | 54.19 | 54.83 | 55.46 | 56.10 | 56.74 | 57.38 | 58.01 |
| $\frac{1}{4}$ | 71.40 | 72.25 | 73.10 | 73.95 | 74.80 | 75.65 | 76.50 | 77.35 |
| $\frac{5}{16}$ | 89.25 | 90.31 | 91.38 | 92.44 | 93.50 | 94.56 | 95.63 | 96.69 |
| $\frac{3}{8}$ | 107.10 | 108.38 | 109.65 | 110.93 | 112.20 | 113.48 | 114.75 | 116.03 |
| $\frac{7}{16}$ | 124.95 | 126.44 | 127.93 | 129.41 | 130.90 | 132.39 | 133.88 | 135.36 |
| $\frac{1}{2}$ | 142.80 | 144.50 | 146.20 | 147.90 | 149.60 | 151.30 | 153.00 | 154.70 |
| $\frac{9}{16}$ | 160.65 | 162.56 | 164.48 | 166.39 | 168.30 | 170.21 | 172.13 | 174.04 |
| $\frac{5}{8}$ | 178.50 | 180.63 | 182.75 | 184.88 | 187.00 | 189.13 | 191.25 | 193.38 |
| $\frac{11}{16}$ | 196.35 | 198.69 | 201.03 | 203.36 | 205.70 | 208.04 | 210.38 | 212.71 |
| $\frac{3}{4}$ | 214.20 | 216.75 | 219.30 | 221.85 | 224.40 | 226.95 | 229.50 | 232.05 |
| $\frac{13}{16}$ | 232.05 | 234.81 | 237.58 | 240.34 | 243.10 | 245.86 | 248.63 | 251.39 |
| $\frac{7}{8}$ | 249.90 | 252.88 | 255.85 | 258.83 | 261.80 | 264.78 | 267.75 | 270.73 |
| $\frac{15}{16}$ | 267.75 | 270.94 | 274.13 | 277.31 | 280.50 | 283.69 | 286.88 | 290.06 |
| 1 | 285.60 | 289.00 | 292.40 | 295.80 | 299.20 | 302.60 | 306.00 | 309.40 |
| $1\frac{1}{16}$ | 303.45 | 307.06 | 310.68 | 314.29 | 317.90 | 321.51 | 325.13 | 328.74 |
| $1\frac{1}{8}$ | 321.30 | 325.13 | 328.95 | 332.78 | 336.60 | 340.43 | 344.25 | 348.08 |
| $1\frac{3}{16}$ | 339.15 | 343.19 | 347.23 | 351.26 | 355.30 | 359.34 | 363.38 | 367.41 |
| $1\frac{1}{4}$ | 357.00 | 361.25 | 365.50 | 369.75 | 374.00 | 378.25 | 382.50 | 386.75 |
| $1\frac{5}{16}$ | 374.85 | 379.31 | 383.78 | 388.24 | 392.70 | 397.16 | 401.63 | 406.09 |
| $1\frac{3}{8}$ | 392.70 | 397.38 | 402.05 | 406.73 | 411.40 | 416.08 | 420.75 | 425.43 |
| $1\frac{7}{16}$ | 410.55 | 415.44 | 420.33 | 425.21 | 430.10 | 434.99 | 439.88 | 444.76 |
| $1\frac{1}{2}$ | 428.40 | 433.50 | 438.60 | 443.70 | 448.80 | 453.90 | 459.00 | 464.10 |
| $1\frac{9}{16}$ | 446.25 | 451.56 | 456.88 | 462.19 | 467.50 | 472.81 | 478.13 | 483.44 |
| $1\frac{5}{8}$ | 464.10 | 469.63 | 475.15 | 480.68 | 486.20 | 491.73 | 497.25 | 502.78 |
| $1\frac{11}{16}$ | 481.95 | 487.69 | 493.43 | 499.16 | 504.90 | 510.64 | 516.38 | 522.11 |
| $1\frac{3}{4}$ | 499.80 | 505.75 | 511.70 | 517.65 | 523.60 | 529.55 | 535.50 | 541.45 |
| $1\frac{13}{16}$ | 517.65 | 523.81 | 529.98 | 536.14 | 542.30 | 548.46 | 554.63 | 560.79 |
| $1\frac{7}{8}$ | 535.50 | 541.88 | 548.25 | 554.63 | 561.00 | 567.38 | 573.75 | 580.13 |
| $1\frac{15}{16}$ | 553.35 | 559.94 | 566.53 | 573.11 | 579.70 | 586.29 | 592.88 | 599.46 |
| 2 | 571.20 | 578.00 | 584.80 | 591.60 | 598.40 | 605.20 | 612.00 | 618.80 |

## Weight of Rectangular Steel Plates per Lineal Foot—(*Cont.*)

| Thickness, in Sixteenths of an Inch | Width, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 |
| | Area, in Square Feet | | | | | | | |
| | 7.667 | 7.750 | 7.833 | 7.917 | 8.000 | 8.083 | 8.167 | 8.250 |
| | Weight, in Pounds | | | | | | | |
| $\frac{1}{16}$ | 19.55 | 19.76 | 19.98 | 20.19 | 20.40 | 20.61 | 20.83 | 21.04 |
| $\frac{1}{8}$ | 39.10 | 39.53 | 39.95 | 40.38 | 40.80 | 41.23 | 41.65 | 42.08 |
| $\frac{3}{16}$ | 58.65 | 59.29 | 59.93 | 60.56 | 61.20 | 61.84 | 62.48 | 63.11 |
| $\frac{1}{4}$ | 78.20 | 79.05 | 79.90 | 80.75 | 81.60 | 82.45 | 83.30 | 84.15 |
| $\frac{5}{16}$ | 97.75 | 98.81 | 99.88 | 100.94 | 102.00 | 103.86 | 104.13 | 105.19 |
| $\frac{3}{8}$ | 117.30 | 118.58 | 119.85 | 121.13 | 122.40 | 123.68 | 124.95 | 126.23 |
| $\frac{7}{16}$ | 136.85 | 138.34 | 139.83 | 141.31 | 142.80 | 144.29 | 145.78 | 147.26 |
| $\frac{1}{2}$ | 156.40 | 158.10 | 159.80 | 161.50 | 163.20 | 164.90 | 166.60 | 168.30 |
| $\frac{9}{16}$ | 175.95 | 177.86 | 179.68 | 181.69 | 183.60 | 185.51 | 187.43 | 189.34 |
| $\frac{5}{8}$ | 195.50 | 197.63 | 199.75 | 201.88 | 204.00 | 206.13 | 208.25 | 210.38 |
| $\frac{11}{16}$ | 215.05 | 217.39 | 219.73 | 222.06 | 224.40 | 226.74 | 229.08 | 231.41 |
| $\frac{3}{4}$ | 234.60 | 237.15 | 239.70 | 242.25 | 244.80 | 247.35 | 249.90 | 252.45 |
| $\frac{13}{16}$ | 254.15 | 256.91 | 259.68 | 262.44 | 265.20 | 267.96 | 270.73 | 273.49 |
| $\frac{7}{8}$ | 273.70 | 276.68 | 279.65 | 282.63 | 285.60 | 288.58 | 291.55 | 294.53 |
| $\frac{15}{16}$ | 293.25 | 296.44 | 299.63 | 302.81 | 306.00 | 309.19 | 312.37 | 315.56 |
| 1 | 312.80 | 316.20 | 319.60 | 323.00 | 326.40 | 329.80 | 333.20 | 336.60 |
| $1\frac{1}{16}$ | 332.35 | 335.96 | 339.58 | 343.19 | 346.80 | 350.41 | 354.03 | 357.64 |
| $1\frac{1}{8}$ | 351.90 | 355.73 | 359.55 | 363.38 | 367.20 | 371.03 | 374.85 | 378.68 |
| $1\frac{3}{16}$ | 371.45 | 375.49 | 379.53 | 383.56 | 387.60 | 391.64 | 395.68 | 399.71 |
| $1\frac{1}{4}$ | 391.00 | 395.25 | 399.50 | 403.75 | 408.00 | 412.25 | 416.50 | 420.75 |
| $1\frac{5}{16}$ | 410.55 | 415.01 | 419.48 | 423.94 | 428.40 | 432.86 | 437.33 | 441.79 |
| $1\frac{3}{8}$ | 430.10 | 434.78 | 439.45 | 444.13 | 448.80 | 453.48 | 458.15 | 462.83 |
| $1\frac{7}{16}$ | 449.65 | 454.54 | 459.43 | 464.31 | 469.20 | 474.09 | 478.98 | 483.86 |
| $1\frac{1}{2}$ | 469.20 | 474.30 | 479.40 | 484.50 | 489.60 | 494.70 | 499.80 | 504.90 |
| $1\frac{9}{16}$ | 488.75 | 494.06 | 499.38 | 504.69 | 510.00 | 515.31 | 520.63 | 525.94 |
| $1\frac{5}{8}$ | 508.30 | 513.83 | 519.35 | 524.88 | 530.40 | 535.93 | 541.45 | 546.98 |
| $1\frac{11}{16}$ | 527.85 | 533.59 | 539.33 | 545.06 | 550.80 | 556.54 | 562.28 | 568.01 |
| $1\frac{3}{4}$ | 547.40 | 553.35 | 559.30 | 565.25 | 571.20 | 577.15 | 583.10 | 589.05 |
| $1\frac{13}{16}$ | 566.95 | 573.11 | 579.28 | 575.44 | 591.60 | 597.76 | 603.93 | 610.09 |
| $1\frac{7}{8}$ | 586.50 | 592.88 | 599.25 | 605.63 | 612.00 | 618.38 | 624.75 | 631.13 |
| $1\frac{15}{16}$ | 606.05 | 612.64 | 619.23 | 625.81 | 632.40 | 638.99 | 645.58 | 652.16 |
| 2 | 625.60 | 632.40 | 639.20 | 646.00 | 652.80 | 659.60 | 666.40 | 673.20 |

WEIGHT OF CIRCULAR STEEL PLATES
Reduction factor: 1 cubic inch of steel = 0.283333 pound

| Thickness, in Sixteenths of an Inch | Diameter, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| | Area, in Square Inches | | | | | | | |
| | 113.10 | 132.73 | 153.94 | 176.72 | 201.06 | 226.98 | 254.47 | 283.53 |
| | Weight, in Pounds | | | | | | | |
| $\frac{1}{16}$ | 2.00 | 2.35 | 2.73 | 3.13 | 3.56 | 4.02 | 4.51 | 5.02 |
| $\frac{1}{8}$ | 4.01 | 4.70 | 5.45 | 6.26 | 7.12 | 8.04 | 9.01 | 10.04 |
| $\frac{3}{16}$ | 6.01 | 7.05 | 8.18 | 9.39 | 10.68 | 12.06 | 13.52 | 15.06 |
| $\frac{1}{4}$ | 8.01 | 9.40 | 10.90 | 12.52 | 14.24 | 16.08 | 18.02 | 20.08 |
| $\frac{5}{16}$ | 10.01 | 11.75 | 13.63 | 16.65 | 17.80 | 20.10 | 22.53 | 25.10 |
| $\frac{3}{8}$ | 12.02 | 14.10 | 16.36 | 18.78 | 21.36 | 24.12 | 27.04 | 30.13 |
| $\frac{7}{16}$ | 14.02 | 16.45 | 19.08 | 21.91 | 24.92 | 28.14 | 31.54 | 35.15 |
| $\frac{1}{2}$ | 16.02 | 18.80 | 21.81 | 25.03 | 28.48 | 32.16 | 36.05 | 40.17 |
| $\frac{9}{16}$ | 18.02 | 21.15 | 24.53 | 28.16 | 32.04 | 36.18 | 40.56 | 45.19 |
| $\frac{5}{8}$ | 20.03 | 23.50 | 27.26 | 31.29 | 35.60 | 40.19 | 45.06 | 50.21 |
| $\frac{11}{16}$ | 22.03 | 25.86 | 29.99 | 34.42 | 39.17 | 44.21 | 49.57 | 55.23 |
| $\frac{3}{4}$ | 24.03 | 28.21 | 32.71 | 37.55 | 42.73 | 48.23 | 54.07 | 60.25 |
| $\frac{13}{16}$ | 26.04 | 30.56 | 35.44 | 40.68 | 46.29 | 52.25 | 58.58 | 65.27 |
| $\frac{7}{8}$ | 28.04 | 32.91 | 38.16 | 43.81 | 49.85 | 56.27 | 63.09 | 70.29 |
| $\frac{15}{16}$ | 30.04 | 35.26 | 40.89 | 46.94 | 53.41 | 60.29 | 67.59 | 75.31 |
| 1 | 32.04 | 37.61 | 43.62 | 50.07 | 56.97 | 64.31 | 72.10 | 80.33 |

| Thickness, in Sixteenths of an Inch | Diameter, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| | Area, in Square Inches | | | | | | | |
| | 314.16 | 346.36 | 380.13 | 415.48 | 452.39 | 490.88 | 530.93 | 572.56 |
| | Weight, in Pounds | | | | | | | |
| $\frac{1}{16}$ | 5.56 | 6.13 | 6.73 | 7.36 | 8.01 | 8.69 | 9.40 | 10.14 |
| $\frac{1}{8}$ | 11.13 | 12.27 | 13.46 | 14.71 | 16.02 | 17.39 | 18.80 | 20.28 |
| $\frac{3}{16}$ | 16.69 | 18.40 | 20.19 | 22.07 | 24.03 | 26.08 | 28.21 | 30.42 |
| $\frac{1}{4}$ | 22.25 | 24.53 | 26.93 | 29.43 | 32.04 | 34.77 | 37.61 | 40.56 |
| $\frac{5}{16}$ | 27.82 | 30.67 | 33.66 | 36.79 | 40.06 | 43.46 | 47.01 | 50.70 |
| $\frac{3}{8}$ | 33.38 | 36.80 | 40.39 | 44.14 | 48.07 | 52.16 | 56.41 | 60.83 |
| $\frac{7}{16}$ | 38.94 | 42.93 | 47.12 | 51.50 | 56.08 | 60.85 | 65.81 | 70.97 |
| $\frac{1}{2}$ | 44.51 | 49.07 | 53.85 | 58.86 | 64.09 | 69.54 | 75.22 | 81.11 |
| $\frac{9}{16}$ | 50.07 | 55.20 | 60.58 | 66.22 | 72.10 | 78.23 | 84.62 | 91.25 |
| $\frac{5}{8}$ | 55.63 | 61.33 | 67.32 | 73.57 | 80.11 | 86.93 | 94.02 | 101.39 |
| $\frac{11}{16}$ | 61.20 | 67.47 | 74.05 | 80.93 | 88.12 | 95.62 | 103.42 | 111.53 |
| $\frac{3}{4}$ | 66.76 | 73.60 | 80.78 | 88.29 | 96.13 | 104.31 | 112.82 | 121.67 |
| $\frac{13}{16}$ | 72.32 | 79.74 | 87.51 | 95.65 | 104.14 | 113.00 | 122.22 | 131.81 |
| $\frac{7}{8}$ | 77.89 | 85.87 | 94.24 | 103.00 | 112.16 | 121.70 | 131.63 | 141.95 |
| $\frac{15}{16}$ | 83.45 | 92.00 | 100.97 | 110.36 | 120.17 | 130.39 | 141.03 | 152.09 |
| 1 | 89.01 | 98.14 | 107.70 | 117.72 | 128.18 | 139.08 | 150.43 | 162.22 |

WEIGHT OF CIRCULAR STEEL PLATES—(*Cont.*)

| Thickness, in Sixteenths of an Inch | Diameter, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 |
| | Area, in Square Inches | | | | | | | |
| | 615.75 | 660.52 | 706.86 | 754.77 | 804.25 | 855.30 | 907.92 | 962.11 |
| | Weight, in Pounds | | | | | | | |
| 1/16 | 10.90 | 11.70 | 12.52 | 13.37 | 14.24 | 15.15 | 16.08 | 17.04 |
| 1/8 | 21.81 | 23.39 | 25.03 | 26.73 | 28.48 | 30.29 | 32.16 | 34.07 |
| 3/16 | 32.71 | 35.09 | 37.55 | 40.10 | 42.73 | 45.44 | 48.23 | 51.11 |
| 1/4 | 43.62 | 46.79 | 50.07 | 53.46 | 56.97 | 60.58 | 64.31 | 68.15 |
| 5/16 | 54.52 | 58.48 | 62.59 | 66.83 | 71.21 | 75.73 | 80.39 | 85.19 |
| 3/8 | 65.42 | 70.18 | 75.10 | 80.19 | 85.45 | 90.88 | 96.47 | 102.22 |
| 7/16 | 76.33 | 81.88 | 87.62 | 93.56 | 99.69 | 106.02 | 112.54 | 119.26 |
| 1/2 | 87.23 | 93.57 | 100.14 | 106.93 | 113.94 | 121.17 | 128.62 | 136.30 |
| 9/16 | 98.14 | 105.27 | 112.66 | 120.29 | 128.18 | 136.31 | 144.70 | 153.34 |
| 5/8 | 109.04 | 116.97 | 125.17 | 133.66 | 142.42 | 151.46 | 160.78 | 170.37 |
| 11/16 | 119.94 | 128.66 | 137.69 | 147.02 | 156.66 | 166.61 | 176.86 | 187.41 |
| 3/4 | 130.85 | 140.36 | 150.21 | 160.39 | 170.90 | 181.75 | 192.93 | 204.45 |
| 13/16 | 141.75 | 152.06 | 162.73 | 173.75 | 185.15 | 196.90 | 209.01 | 221.49 |
| 7/8 | 152.66 | 163.75 | 175.24 | 187.12 | 199.39 | 212.04 | 225.09 | 238.52 |
| 15/16 | 163.56 | 175.45 | 187.76 | 200.49 | 213.63 | 227.19 | 241.17 | 255.56 |
| 1 | 174.46 | 187.15 | 200.28 | 213.85 | 227.87 | 242.34 | 257.24 | 272.60 |

| Thickness, in Sixteenths of an Inch | Diameter, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 |
| | Area, in Square Inches | | | | | | | |
| | 1017.87 | 1075.21 | 1134.11 | 1194.59 | 1256.64 | 1320.25 | 1385.44 | 1452.20 |
| | Weight, in Pounds | | | | | | | |
| 1/16 | 18.02 | 19.04 | 20.08 | 21.15 | 22.25 | 23.38 | 24.53 | 25.72 |
| 1/8 | 36.05 | 38.08 | 40.17 | 42.31 | 44.51 | 46.76 | 49.07 | 51.43 |
| 3/16 | 54.07 | 57.12 | 60.25 | 63.46 | 66.76 | 70.14 | 73.60 | 77.15 |
| 1/4 | 72.10 | 76.16 | 80.33 | 84.62 | 89.01 | 93.52 | 98.14 | 102.86 |
| 5/16 | 90.12 | 95.20 | 100.42 | 105.77 | 111.27 | 116.90 | 122.67 | 128.58 |
| 3/8 | 108.15 | 114.24 | 120.50 | 126.93 | 133.52 | 140.28 | 147.20 | 154.30 |
| 7/16 | 126.17 | 133.28 | 140.58 | 148.08 | 155.77 | 163.66 | 171.74 | 180.01 |
| 1/2 | 144.20 | 152.32 | 160.67 | 169.23 | 178.02 | 187.04 | 196.27 | 205.73 |
| 9/16 | 162.22 | 171.36 | 180.75 | 190.39 | 200.28 | 210.42 | 220.81 | 231.44 |
| 5/8 | 180.25 | 190.40 | 200.83 | 211.54 | 222.53 | 233.79 | 245.34 | 257.16 |
| 11/16 | 198.27 | 209.44 | 220.92 | 232.70 | 244.78 | 257.17 | 269.87 | 282.88 |
| 3/4 | 216.30 | 228.48 | 241.00 | 253.85 | 267.04 | 280.55 | 294.41 | 308.59 |
| 13/16 | 234.32 | 247.52 | 261.08 | 275.01 | 289.29 | 303.93 | 318.94 | 334.31 |
| 7/8 | 252.35 | 266.56 | 281.17 | 296.16 | 311.54 | 327.31 | 343.47 | 360.03 |
| 15/16 | 270.37 | 285.60 | 301.25 | 317.31 | 333.80 | 350.69 | 368.01 | 385.74 |
| 1 | 288.40 | 304.64 | 321.33 | 338.47 | 356.05 | 374.07 | 392.54 | 411.46 |

WEIGHT OF CIRCULAR STEEL PLATES—(*Cont.*)

| Thickness, in Sixteenths of an Inch | Diameter, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 |
| | Area, in Square Inches | | | | | | | |
| | 1520.53 | 1590.43 | 1661.90 | 1734.94 | 1809.56 | 1885.74 | 1963.50 | 2042.82 |
| | Weight, in Pounds | | | | | | | |
| 1/16 | 26.93 | 28.16 | 29.43 | 30.72 | 32.04 | 33.39 | 34.77 | 36.18 |
| 1/8 | 53.85 | 56.33 | 58.86 | 61.45 | 64.09 | 66.79 | 69.54 | 72.35 |
| 3/16 | 80.78 | 84.49 | 88.29 | 92.17 | 96.13 | 100.18 | 104.31 | 108.53 |
| 1/4 | 107.70 | 112.66 | 117.72 | 122.89 | 128.18 | 133.57 | 139.08 | 144.70 |
| 5/16 | 134.63 | 140.82 | 147.15 | 153.61 | 160.22 | 166.97 | 173.85 | 180.88 |
| 3/8 | 161.56 | 168.98 | 176.58 | 184.34 | 192.27 | 200.36 | 208.62 | 217.05 |
| 7/16 | 188.48 | 197.15 | 206.01 | 215.06 | 224.31 | 233.75 | 243.39 | 253.23 |
| 1/2 | 215.41 | 225.31 | 235.44 | 245.78 | 256.35 | 267.15 | 278.16 | 289.40 |
| 9/16 | 242.34 | 253.48 | 264.87 | 276.51 | 288.40 | 300.54 | 312.93 | 325.58 |
| 5/8 | 269.26 | 281.64 | 294.30 | 307.23 | 320.44 | 333.93 | 347.70 | 361.75 |
| 11/16 | 296.19 | 309.80 | 323.73 | 337.95 | 352.49 | 367.33 | 382.47 | 397.93 |
| 3/4 | 323.11 | 337.97 | 353.15 | 368.68 | 384.53 | 400.72 | 417.24 | 434.10 |
| 13/16 | 350.04 | 366.13 | 382.58 | 399.40 | 416.58 | 434.11 | 452.02 | 470.28 |
| 7/8 | 376.97 | 394.30 | 412.01 | 430.12 | 448.62 | 467.51 | 486.79 | 506.45 |
| 15/16 | 403.89 | 422.46 | 441.44 | 460.84 | 480.67 | 500.90 | 521.56 | 542.63 |
| 1 | 430.82 | 450.62 | 470.87 | 491.57 | 512.71 | 534.29 | 556.33 | 578.80 |

| Thickness, in Sixteenths of an Inch | Diameter, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 |
| | Area, in Square Inches | | | | | | | |
| | 2123.72 | 2206.18 | 2290.22 | 2375.83 | 2463.01 | 2551.76 | 2642.08 | 2733.97] |
| | Weight, in Pounds | | | | | | | |
| 1/16 | 37.61 | 39.07 | 40.56 | 42.07 | 43.62 | 45.19 | 46.79 | 48.41 |
| 1/8 | 75.22 | 78.14 | 81.11 | 84.14 | 87.23 | 90.38 | 93.57 | 96.83 |
| 3/16 | 112.82 | 117.20 | 121.67 | 126.22 | 130.85 | 135.56 | 140.36 | 145.24 |
| 1/4 | 150.43 | 156.27 | 162.22 | 168.29 | 174.46 | 180.75 | 187.15 | 193.66 |
| 5/16 | 188.04 | 195.34 | 202.78 | 210.36 | 218.08 | 225.94 | 233.93 | 242.07 |
| 3/8 | 225.65 | 234.41 | 243.34 | 252.43 | 261.70 | 271.13 | 280.72 | 290.48 |
| 7/16 | 263.25 | 273.48 | 283.89 | 294.50 | 305.31 | 316.31 | 327.51 | 338.90 |
| 1/2 | 300.86 | 312.54 | 324.45 | 336.58 | 348.93 | 361.50 | 374.30 | 387.31 |
| 9/16 | 338.47 | 351.61 | 365.00 | 378.65 | 392.54 | 406.69 | 421.08 | 435.73 |
| 5/8 | 376.08 | 390.68 | 405.56 | 420.72 | 436.16 | 451.88 | 467.87 | 484.14 |
| 11/16 | 413.68 | 429.75 | 446.12 | 462.79 | 479.77 | 497.06 | 514.66 | 532.56 |
| 3/4 | 451.29 | 468.81 | 486.67 | 504.87 | 523.39 | 542.25 | 561.44 | 580.97 |
| 13/16 | 488.90 | 507.88 | 527.23 | 546.94 | 567.01 | 587.44 | 608.23 | 629.38 |
| 7/8 | 526.51 | 546.95 | 567.79 | 589.01 | 610.62 | 632.63 | 655.02 | 677.80 |
| 15/16 | 564.11 | 586.02 | 608.34 | 631.08 | 654.24 | 677.81 | 701.80 | 726.21 |
| 1 | 601.72 | 625.09 | 648.90 | 673.15 | 697.85 | 723.00 | 748.59 | 774.63 |

WEIGHT OF CIRCULAR STEEL PLATES—(*Cont.*)

| Thickness, in Sixteenths of an Inch | Diameter, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 |
| | Area, in Square Inches | | | | | | | |
| | 2827.44 | 2922.47 | 3019.07 | 3117.25 | 3216.99 | 3318.31 | 3421.20 | 3525.66 |
| | Weight, in Pounds | | | | | | | |
| 1/16 | 50.07 | 51.75 | 53.46 | 55.20 | 56.97 | 58.76 | 60.58 | 62.43 |
| 1/8 | 100.14 | 103.50 | 106.93 | 110.40 | 113.94 | 117.52 | 121.17 | 124.87 |
| 3/16 | 150.21 | 155.26 | 160.39 | 165.60 | 170.90 | 176.29 | 181.75 | 187.30 |
| 1/4 | 200.28 | 207.01 | 213.85 | 220.81 | 227.87 | 235.05 | 242.34 | 249.73 |
| 5/16 | 250.35 | 258.76 | 267.31 | 276.01 | 284.84 | 293.81 | 302.92 | 312.17 |
| 3/8 | 300.42 | 310.51 | 320.78 | 331.21 | 341.81 | 352.57 | 363.50 | 374.60 |
| 7/16 | 350.49 | 362.27 | 374.24 | 386.41 | 398.77 | 411.33 | 424.09 | 437.04 |
| 1/2 | 400.55 | 414.02 | 427.70 | 441.61 | 455.74 | 470.10 | 484.67 | 499.47 |
| 9/16 | 450.62 | 465.77 | 481.17 | 496.81 | 512.71 | 528.86 | 545.26 | 561.90 |
| 5/8 | 500.69 | 517.52 | 534.63 | 552.01 | 569.68 | 587.62 | 605.84 | 624.34 |
| 11/16 | 550.76 | 569.27 | 588.09 | 607.22 | 626.64 | 646.38 | 666.42 | 686.77 |
| 3/4 | 600.83 | 621.03 | 641.55 | 662.42 | 683.61 | 705.14 | 727.01 | 749.20 |
| 13/16 | 650.90 | 672.78 | 695.02 | 717.62 | 740.58 | 763.90 | 787.59 | 811.64 |
| 7/8 | 700.97 | 724.53 | 748.48 | 772.82 | 797.55 | 822.67 | 848.17 | 874.07 |
| 15/16 | 751.04 | 776.28 | 801.94 | 828.02 | 854.51 | 881.43 | 908.76 | 936.51 |
| 1 | 801.11 | 828.04 | 855.41 | 883.22 | 911.48 | 940.19 | 969.34 | 998.94 |

| Thickness, in Sixteenths of an Inch | Diameter, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 |
| | Area, in Square Inches | | | | | | | |
| | 3631.68 | 3739.28 | 3848.46 | 3959.20 | 4071.51 | 4185.39 | 4300.85 | 4417.87 |
| | Weight, in Pounds | | | | | | | |
| 1/16 | 64.31 | 66.22 | 68.15 | 70.11 | 72.10 | 74.12 | 76.16 | 78.23 |
| 1/8 | 128.62 | 132.43 | 136.30 | 140.22 | 144.20 | 148.23 | 152.32 | 156.47 |
| 3/16 | 192.93 | 198.65 | 204.45 | 210.33 | 216.30 | 222.35 | 228.48 | 234.70 |
| 1/4 | 257.24 | 264.87 | 272.60 | 280.44 | 288.40 | 296.47 | 304.64 | 312.93 |
| 5/16 | 321.56 | 331.08 | 340.75 | 350.56 | 360.50 | 370.58 | 380.81 | 391.17 |
| 3/8 | 385.87 | 397.30 | 408.90 | 420.67 | 432.60 | 444.70 | 456.97 | 469.40 |
| 7/16 | 450.18 | 463.52 | 477.05 | 490.78 | 504.70 | 518.82 | 533.13 | 547.63 |
| 1/2 | 514.49 | 529.73 | 545.20 | 560.89 | 576.80 | 592.93 | 609.29 | 625.87 |
| 9/16 | 578.80 | 595.95 | 613.35 | 631.00 | 648.90 | 667.05 | 685.45 | 704.10 |
| 5/8 | 643.11 | 662.17 | 681.50 | 701.11 | 721.00 | 741.16 | 761.61 | 782.33 |
| 11/16 | 707.42 | 728.38 | 749.65 | 771.22 | 793.10 | 815.28 | 837.77 | 860.57 |
| 3/4 | 771.73 | 794.60 | 817.80 | 841.33 | 865.20 | 889.40 | 913.93 | 938.80 |
| 13/16 | 836.04 | 860.82 | 885.95 | 911.44 | 937.30 | 963.51 | 990.09 | 1017.0 |
| 7/8 | 900.36 | 927.03 | 954.10 | 981.55 | 1009.4 | 1037.6 | 1066.3 | 1095.3 |
| 15/16 | 964.67 | 993.25 | 1022.2 | 1051.7 | 1081.5 | 1111.7 | 1142.4 | 1173.5 |
| 1 | 1029.0 | 1059.5 | 1090.4 | 1121.8 | 1153.6 | 1185.9 | 1218.6 | 1251.7 |

WEIGHT OF CIRCULAR STEEL PLATES—(*Cont.*)

| Thickness, in Sixteenths of an Inch | Diameter, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 |
| | Area, in Square Inches | | | | | | | |
| | 4536.47 | 4656.63 | 4778.37 | 4901.68 | 5026.56 | 5153.00 | 5281.02 | 5410.62 |
| | Weight, in Pounds | | | | | | | |
| $\frac{1}{16}$ | 80.33 | 82.46 | 84.62 | 86.80 | 89.01 | 91.25 | 93.52 | 95.81 |
| $\frac{1}{8}$ | 160.67 | 164.92 | 169.23 | 173.60 | 178.02 | 182.50 | 187.04 | 191.63 |
| $\frac{3}{16}$ | 241.00 | 247.38 | 253.85 | 260.40 | 267.04 | 273.75 | 280.55 | 287.44 |
| $\frac{1}{4}$ | 321.33 | 329.85 | 338.47 | 347.20 | 356.05 | 365.01 | 374.07 | 383.25 |
| $\frac{5}{16}$ | 401.67 | 412.31 | 423.09 | 434.00 | 445.06 | 456.26 | 467.59 | 479.07 |
| $\frac{3}{8}$ | 482.00 | 494.77 | 507.70 | 520.80 | 534.07 | 547.51 | 561.11 | 574.88 |
| $\frac{7}{16}$ | 562.33 | 577.23 | 592.32 | 607.61 | 623.09 | 638.76 | 654.63 | 670.69 |
| $\frac{1}{2}$ | 642.67 | 659.69 | 676.94 | 694.41 | 712.10 | 730.01 | 748.15 | 766.51 |
| $\frac{9}{16}$ | 723.00 | 742.15 | 761.55 | 781.21 | 801.11 | 821.26 | 841.66 | 862.32 |
| $\frac{5}{8}$ | 803.34 | 824.61 | 846.17 | 868.01 | 890.12 | 912.51 | 935.18 | 958.13 |
| $\frac{11}{16}$ | 883.67 | 907.07 | 930.79 | 954.81 | 979.13 | 1003.8 | 1028.7 | 1053.9 |
| $\frac{3}{4}$ | 964.00 | 989.54 | 1015.4 | 1041.6 | 1068.1 | 1095.0 | 1122.2 | 1149.8 |
| $\frac{13}{16}$ | 1044.3 | 1072.0 | 1100.0 | 1128.4 | 1157.2 | 1186.3 | 1215.7 | 1245.6 |
| $\frac{7}{8}$ | 1124.7 | 1154.5 | 1184.6 | 1215.2 | 1246.2 | 1277.5 | 1309.3 | 1341.4 |
| $\frac{15}{16}$ | 1205.0 | 1236.9 | 1269.3 | 1302.0 | 1335.2 | 1368.8 | 1402.8 | 1437.2 |
| 1 | 1285.3 | 1319.4 | 1353.9 | 1388.8 | 1424.2 | 1460.0 | 1496.3 | 1533.0 |

| Thickness, in Sixteenths of an Inch | Diameter, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 |
| | Area, in Square Inches | | | | | | | |
| | 5541.78 | 5674.51 | 5808.81 | 5944.69 | 6082.13 | 6221.15 | 6361.74 | 6503.89 |
| | Weight, in Pounds | | | | | | | |
| $\frac{1}{16}$ | 98.14 | 100.49 | 102.86 | 105.27 | 107.70 | 110.17 | 112.66 | 115.17 |
| $\frac{1}{8}$ | 196.27 | 200.97 | 205.73 | 210.54 | 215.41 | 220.33 | 225.31 | 230.35 |
| $\frac{3}{16}$ | 294.41 | 301.46 | 308.59 | 315.81 | 323.11 | 330.50 | 337.97 | 345.52 |
| $\frac{1}{4}$ | 392.54 | 401.95 | 411.46 | 421.08 | 430.82 | 440.67 | 450.62 | 460.69 |
| $\frac{5}{16}$ | 490.68 | 502.43 | 514.32 | 526.35 | 538.52 | 550.83 | 563.28 | 575.87 |
| $\frac{3}{8}$ | 588.82 | 602.92 | 617.19 | 631.62 | 646.23 | 661.00 | 675.94 | 691.04 |
| $\frac{7}{16}$ | 686.95 | 703.40 | 720.05 | 736.90 | 753.93 | 771.17 | 788.59 | 806.21 |
| $\frac{1}{2}$ | 785.09 | 803.89 | 822.92 | 842.17 | 861.64 | 881.33 | 901.25 | 921.39 |
| $\frac{9}{16}$ | 883.22 | 904.38 | 925.78 | 947.44 | 969.34 | 991.50 | 1013.9 | 1036.6 |
| $\frac{5}{8}$ | 981.36 | 1004.9 | 1028.6 | 1052.7 | 1077.0 | 1101.7 | 1126.6 | 1151.7 |
| $\frac{11}{16}$ | 1079.5 | 1105.3 | 1131.5 | 1158.0 | 1184.8 | 1211.8 | 1239.2 | 1266.9 |
| $\frac{3}{4}$ | 1177.6 | 1205.8 | 1234.4 | 1263.2 | 1292.5 | 1322.0 | 1351.9 | 1382.1 |
| $\frac{13}{16}$ | 1275.8 | 1306.3 | 1337.2 | 1368.5 | 1400.2 | 1432.2 | 1464.5 | 1497.3 |
| $\frac{7}{8}$ | 1373.9 | 1406.8 | 1440.1 | 1473.8 | 1507.9 | 1542.3 | 1577.2 | 1612.4 |
| $\frac{15}{16}$ | 1472.0 | 1507.3 | 1543.0 | 1579.1 | 1615.6 | 1652.5 | 1689.8 | 1727.6 |
| 1 | 1570.2 | 1607.8 | 1645.8 | 1684.3 | 1723.3 | 1762.7 | 1802.5 | 1842.8 |

WEIGHT OF CIRCULAR STEEL PLATES—(*Cont.*)

| Thickness, in Sixteenths of an Inch | Diameter, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 |
| | Area, in Square Inches | | | | | | | |
| | 6647.62 | 6792.92 | 6939.79 | 7088.23 | 7238.24 | 7389.80 | 7542.96 | 7697.68 |
| | Weight, in Pounds | | | | | | | |
| 1/16 | 117.72 | 120.29 | 122.89 | 125.52 | 128.18 | 130.86 | 133.57 | 136.31 |
| 1/8 | 235.44 | 240.58 | 245.78 | 251.04 | 256.35 | 261.72 | 267.15 | 272.63 |
| 3/16 | 353.16 | 360.87 | 368.68 | 376.56 | 384.53 | 392.58 | 400.72 | 408.94 |
| 1/4 | 470.87 | 481.17 | 491.57 | 502.08 | 512.71 | 523.45 | 534.29 | 545.25 |
| 5/16 | 588.59 | 601.46 | 614.46 | 627.61 | 640.89 | 654.31 | 667.87 | 681.57 |
| 3/8 | 706.31 | 721.75 | 737.35 | 753.13 | 769.06 | 785.17 | 801.44 | 817.88 |
| 7/16 | 824.03 | 842.04 | 860.25 | 878.65 | 897.24 | 916.03 | 935.01 | 954.19 |
| 1/2 | 941.75 | 962.33 | 983.14 | 1004.2 | 1025.4 | 1046.9 | 1068.6 | 1090.5 |
| 9/16 | 1059.5 | 1082.6 | 1106.0 | 1129.7 | 1153.6 | 1177.8 | 1202.2 | 1226.8 |
| 5/8 | 1177.2 | 1202.9 | 1228.9 | 1255.2 | 1281.8 | 1308.6 | 1335.7 | 1363.1 |
| 11/16 | 1294.9 | 1323.2 | 1351.8 | 1380.7 | 1410.0 | 1439.5 | 1469.3 | 1499.4 |
| 3/4 | 1412.6 | 1443.5 | 1474.7 | 1506.3 | 1538.1 | 1570.3 | 1602.9 | 1635.8 |
| 13/16 | 1530.3 | 1563.8 | 1597.6 | 1631.8 | 1666.3 | 1701.2 | 1736.5 | 1772.1 |
| 7/8 | 1648.1 | 1684.1 | 1720.5 | 1757.3 | 1794.5 | 1832.1 | 1870.0 | 1908.4 |
| 15/16 | 1765.8 | 1804.4 | 1743.4 | 1882.8 | 1922.7 | 1962.9 | 2003.6 | 2044.7 |
| 1 | 1883.5 | 1924.7 | 1966.3 | 2008.3 | 2050.8 | 2093.8 | 2137.2 | 2181.0 |

| Thickness, in Sixteenths of an Inch | Diameter, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 |
| | Area, in Square Inches | | | | | | | |
| | 7854.00 | 8011.84 | 8171.28 | 8332.29 | 8494.87 | 8659.01 | 8824.73 | 8992.02 |
| | Weight, in Pounds | | | | | | | |
| 1/16 | 139.08 | 141.88 | 144.70 | 147.55 | 150.43 | 153.34 | 156.27 | 159.23 |
| 1/8 | 278.16 | 283.75 | 289.49 | 295.10 | 300.86 | 306.67 | 312.54 | 318.47 |
| 3/16 | 417.24 | 425.63 | 434.10 | 442.65 | 451.29 | 460.01 | 468.81 | 477.70 |
| 1/4 | 556.33 | 567.51 | 578.80 | 590.21 | 601.72 | 613.35 | 625.09 | 636.94 |
| 5/16 | 695.41 | 709.38 | 723.50 | 737.76 | 752.15 | 766.68 | 781.36 | 796.17 |
| 3/8 | 834.49 | 851.26 | 868.20 | 885.31 | 902.58 | 920.02 | 937.63 | 955.40 |
| 7/16 | 973.57 | 993.14 | 1012.9 | 1032.9 | 1053.0 | 1073.4 | 1093.9 | 1114.6 |
| 1/2 | 1112.7 | 1135.0 | 1157.6 | 1180.4 | 1203.4 | 1226.7 | 1250.2 | 1273.9 |
| 9/16 | 1251.7 | 1276.9 | 1302.3 | 1328.0 | 1353.9 | 1380.0 | 1406.4 | 1433.1 |
| 5/8 | 1390.8 | 1418.8 | 1447.0 | 1475.5 | 1504.3 | 1533.4 | 1562.7 | 1592.3 |
| 11/16 | 1529.9 | 1560.6 | 1591.7 | 1623.1 | 1654.7 | 1686.7 | 1719.0 | 1751.6 |
| 3/4 | 1669.0 | 1702.5 | 1736.4 | 1770.6 | 1805.2 | 1840.0 | 1875.3 | 1910.8 |
| 13/16 | 1808.1 | 1844.4 | 1881.1 | 1918.2 | 1955.6 | 1993.4 | 2031.5 | 2070.0 |
| 7/8 | 1947.1 | 1986.3 | 2025.8 | 2065.7 | 2106.0 | 2146.7 | 2187.8 | 2229.3 |
| 15/16 | 2086.2 | 2128.2 | 2170.5 | 2213.2 | 2256.5 | 2300.1 | 2344.1 | 2388.5 |
| 1 | 2225.3 | 2270.0 | 2315.2 | 2360.8 | 2406.9 | 2453.4 | 2500.4 | 2547.7 |

WEIGHT OF CIRCULAR STEEL PLATES—(*Cont.*)

| Thickness, in Sixteenths of an Inch | Diameter in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 |
| | Area, in Square Inches | | | | | | | |
| | 9160.88 | 9331.32 | 9503.32 | 9676.89 | 9852.03 | 10028.75 | 10207.03 | 10386.89 |
| | Weight, in Pounds | | | | | | | |
| $\frac{1}{16}$ | 162.22 | 165.24 | 168.29 | 171.36 | 174.76 | 177.59 | 180.75 | 183.93 |
| $\frac{1}{8}$ | 324.45 | 330.49 | 336.58 | 342.72 | 348.93 | 355.19 | 361.50 | 367.87 |
| $\frac{3}{16}$ | 486.67 | 495.73 | 504.87 | 514.09 | 523.39 | 532.78 | 542.25 | 551.80 |
| $\frac{1}{4}$ | 648.90 | 660.97 | 673.15 | 685.45 | 697.85 | 710.37 | 723.00 | 735.74 |
| $\frac{5}{16}$ | 811.12 | 826.21 | 841.44 | 856.81 | 872.32 | 887.96 | 903.75 | 919.67 |
| $\frac{3}{8}$ | 973.35 | 991.46 | 1009.7 | 1028.2 | 1046.8 | 1065.6 | 1084.5 | 1103.6 |
| $\frac{7}{16}$ | 1135.6 | 1156.7 | 1178.0 | 1199.5 | 1221.2 | 1243.2 | 1265.2 | 1287.5 |
| $\frac{1}{2}$ | 1297.8 | 1321.9 | 1346.3 | 1370.9 | 1395.7 | 1420.7 | 1446.0 | 1471.5 |
| $\frac{9}{16}$ | 1460.0 | 1487.2 | 1514.6 | 1542.3 | 1570.2 | 1598.3 | 1626.7 | 1655.4 |
| $\frac{5}{8}$ | 1622.2 | 1652.4 | 1682.9 | 1713.6 | 1744.6 | 1775.9 | 1807.6 | 1839.3 |
| $\frac{11}{16}$ | 1784.5 | 1817.7 | 1851.2 | 1885.0 | 1919.1 | 1953.5 | 1988.2 | 2023.3 |
| $\frac{3}{4}$ | 1946.7 | 1982.9 | 2019.5 | 2056.3 | 2093.6 | 2131.1 | 2169.0 | 2207.2 |
| $\frac{13}{16}$ | 2108.9 | 2148.2 | 2187.7 | 2227.7 | 2268.0 | 2308.7 | 2349.7 | 2391.2 |
| $\frac{7}{8}$ | 2271.1 | 2313.4 | 2356.0 | 2399.1 | 2442.5 | 2486.3 | 2530.5 | 2575.1 |
| $\frac{15}{16}$ | 2433.4 | 2478.6 | 2524.3 | 2570.4 | 2617.0 | 2663.9 | 2711.2 | 2759.0 |
| 1 | 2595.6 | 2643.9 | 2692.6 | 2741.8 | 2791.4 | 2841.5 | 2892.0 | 2943.0 |

| Thickness, in Sixteenths of an Inch | Diameter, in Inches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 116 | 117 | 118 | 119 | 120 | | | |
| | Area, in Square Inches | | | | | | | |
| | 10568.32 | 10751.32 | 10935.88 | 11122.02 | 11309.73 | | | |
| | Weight, in Pounds | | | | | | | |
| $\frac{1}{16}$ | 187.15 | 190.39 | 193.66 | 196.95 | 200.28 | | | |
| $\frac{1}{8}$ | 374.30 | 380.78 | 387.31 | 393.91 | 400.55 | | | |
| $\frac{3}{16}$ | 561.44 | 571.17 | 580.97 | 590.86 | 600.83 | | | |
| $\frac{1}{4}$ | 748.59 | 761.55 | 774.63 | 787.81 | 801.11 | | | |
| $\frac{5}{16}$ | 935.74 | 951.94 | 968.28 | 984.76 | 1001.4 | | | |
| $\frac{3}{8}$ | 1122.9 | 1142.3 | 1161.9 | 1181.7 | 1201.7 | | | |
| $\frac{7}{16}$ | 1310.0 | 1332.7 | 1355.6 | 1378.7 | 1401.9 | | | |
| $\frac{1}{2}$ | 1497.2 | 1523.1 | 1549.3 | 1575.6 | 1602.2 | | | |
| $\frac{9}{16}$ | 1684.3 | 1713.5 | 1742.9 | 1772.6 | 1802.5 | | | |
| $\frac{5}{8}$ | 1871.5 | 1903.9 | 1936.6 | 1969.5 | 2002.8 | | | |
| $\frac{11}{16}$ | 2058.6 | 2094.3 | 2130.2 | 2166.5 | 2203.0 | | | |
| $\frac{3}{4}$ | 2245.8 | 2284.7 | 2323.9 | 2363.4 | 2403.3 | | | |
| $\frac{13}{16}$ | 2432.9 | 2475.0 | 2517.5 | 2560.4 | 2603.6 | | | |
| $\frac{7}{8}$ | 2620.1 | 2665.4 | 2711.2 | 2757.3 | 2803.9 | | | |
| $\frac{15}{16}$ | 2807.2 | 2855.8 | 2904.9 | 2954.3 | 3004.2 | | | |
| 1 | 2994.4 | 3046.2 | 3098.5 | 3151.2 | 3204.4 | | | |

## Weights of Square and Round Steel Bars.

Reduction Factor: 1 cubic inch of steel = 0.28333 pound.

| Size in Inches | Square Bars | | Round Bars | | Size in Inches | Square Bars | | Round Bars | |
|---|---|---|---|---|---|---|---|---|---|
| | Per Foot | Per Inch | Per Foot | Per Inch | | Per Foot | Per Inch | Per Foot | Per Inch |
| $\frac{1}{4}$ | .213 | .018 | .167 | .014 | $2\frac{3}{4}$ | 25.71 | 2.14 | 20.20 | 1.68 |
| $\frac{5}{16}$ | .332 | .028 | .261 | .022 | $2\frac{13}{16}$ | 26.90 | 2.24 | 21.12 | 1.76 |
| $\frac{3}{8}$ | .478 | .040 | .376 | .031 | $2\frac{7}{8}$ | 28.10 | 2.34 | 22.07 | 1.84 |
| $\frac{7}{16}$ | .651 | .054 | .511 | .043 | $2\frac{15}{16}$ | 29.34 | 2.45 | 23.04 | 1.92 |
| $\frac{1}{2}$ | .850 | .071 | .668 | .056 | 3 | 30.60 | 2.55 | 24.03 | 2.00 |
| $\frac{9}{16}$ | 1.076 | .090 | .845 | .070 | $3\frac{1}{16}$ | 31.89 | 2.66 | 25.05 | 2.08 |
| $\frac{5}{8}$ | 1.328 | .111 | 1.043 | .087 | $3\frac{1}{8}$ | 33.20 | 2.77 | 26.08 | 2.17 |
| $\frac{11}{16}$ | 1.607 | .134 | 1.262 | .105 | $3\frac{3}{16}$ | 34.54 | 2.88 | 27.13 | 2.26 |
| $\frac{3}{4}$ | 1.913 | .159 | 1.502 | .125 | $3\frac{1}{4}$ | 35.91 | 2.99 | 28.21 | 2.35 |
| $\frac{13}{16}$ | 2.245 | .187 | 1.763 | .147 | $3\frac{5}{16}$ | 37.31 | 3.11 | 29.30 | 2.44 |
| $\frac{7}{8}$ | 2.603 | .217 | 2.044 | .170 | $3\frac{3}{8}$ | 38.73 | 3.23 | 30.42 | 2.53 |
| $\frac{15}{16}$ | 2.988 | .250 | 2.347 | .195 | $3\frac{7}{16}$ | 40.18 | 3.35 | 31.55 | 2.63 |
| 1 | 3.40 | .28 | 2.67 | .22 | $3\frac{1}{2}$ | 41.65 | 3.48 | 32.71 | 2.72 |
| $1\frac{1}{16}$ | 3.84 | .32 | 3.02 | .25 | $3\frac{9}{16}$ | 43.15 | 3.60 | 33.89 | 2.82 |
| $1\frac{1}{8}$ | 4.30 | .35 | 3.38 | .28 | $3\frac{5}{8}$ | 44.68 | 3.72 | 35.09 | 2.92 |
| $1\frac{3}{16}$ | 4.79 | .40 | 3.77 | .31 | $3\frac{11}{16}$ | 46.23 | 3.85 | 36.31 | 3.02 |
| $1\frac{1}{4}$ | 5.31 | .44 | 4.17 | .35 | $3\frac{3}{4}$ | 47.81 | 3.98 | 37.55 | 3.13 |
| $1\frac{5}{16}$ | 5.86 | .49 | 4.60 | .38 | $3\frac{13}{16}$ | 49.42 | 4.12 | 38.81 | 3.23 |
| $1\frac{3}{8}$ | 6.43 | .54 | 5.05 | .42 | $3\frac{7}{8}$ | 51.05 | 4.25 | 40.10 | 3.34 |
| $1\frac{7}{16}$ | 7.03 | .59 | 5.52 | .46 | $3\frac{15}{16}$ | 52.71 | 4.39 | 41.40 | 3.45 |
| $1\frac{1}{2}$ | 7.65 | .64 | 6.01 | .50 | 4 | 54.40 | 4.53 | 42.73 | 3.56 |
| $1\frac{9}{16}$ | 8.30 | .69 | 6.52 | .54 | $4\frac{1}{16}$ | 56.11 | 4.68 | 44.07 | 3.67 |
| $1\frac{5}{8}$ | 8.98 | .75 | 7.05 | .59 | $4\frac{1}{8}$ | 57.85 | 4.82 | 45.44 | 3.78 |
| $1\frac{11}{16}$ | 9.68 | .81 | 7.60 | .63 | $4\frac{3}{16}$ | 59.62 | 4.97 | 46.83 | 3.90 |
| $1\frac{3}{4}$ | 10.41 | .87 | 8.18 | .68 | $4\frac{1}{4}$ | 61.41 | 5.12 | 48.23 | 4.01 |
| $1\frac{13}{16}$ | 11.17 | .93 | 8.77 | .73 | $4\frac{5}{16}$ | 63.23 | 5.27 | 49.66 | 4.13 |
| $1\frac{7}{8}$ | 11.95 | 1.00 | 9.39 | .78 | $4\frac{3}{8}$ | 65.08 | 5.42 | 51.11 | 4.25 |
| $1\frac{15}{16}$ | 12.76 | 1.06 | 10.02 | .83 | $4\frac{7}{16}$ | 66.95 | 5.58 | 52.58 | 4.38 |
| 2 | 13.60 | 1.13 | 10.68 | .89 | $4\frac{1}{2}$ | 68.85 | 5.74 | 54.07 | 4.50 |
| $2\frac{1}{16}$ | 14.46 | 1.21 | 11.36 | .94 | $4\frac{9}{16}$ | 70.78 | 5.90 | 55.59 | 4.63 |
| $2\frac{1}{8}$ | 15.35 | 1.28 | 12.06 | 1.00 | $4\frac{5}{8}$ | 72.73 | 6.06 | 57.12 | 4.75 |
| $2\frac{3}{16}$ | 16.27 | 1.36 | 12.78 | 1.06 | $4\frac{11}{16}$ | 74.71 | 6.23 | 58.67 | 4.88 |
| $2\frac{1}{4}$ | 17.21 | 1.43 | 13.52 | 1.13 | $4\frac{3}{4}$ | 76.71 | 6.39 | 60.25 | 5.01 |
| $2\frac{5}{16}$ | 18.18 | 1.52 | 14.28 | 1.19 | $4\frac{13}{16}$ | 78.74 | 6.56 | 61.85 | 5.15 |
| $2\frac{3}{8}$ | 19.18 | 1.60 | 15.06 | 1.25 | $4\frac{7}{8}$ | 80.80 | 6.73 | 63.46 | 5.28 |
| $2\frac{7}{16}$ | 20.20 | 1.68 | 15.87 | 1.33 | $4\frac{15}{16}$ | 82.89 | 6.91 | 65.10 | 5.42 |
| $2\frac{1}{2}$ | 21.25 | 1.77 | 16.69 | 1.39 | 5 | 85.00 | 7.08 | 66.76 | 5.56 |
| $2\frac{9}{16}$ | 22.33 | 1.86 | 17.53 | 1.46 | $5\frac{1}{16}$ | 87.14 | 7.26 | 68.44 | 5.70 |
| $2\frac{5}{8}$ | 23.43 | 1.95 | 18.40 | 1.53 | $5\frac{1}{8}$ | 89.30 | 7.44 | 70.14 | 5.84 |
| $2\frac{11}{16}$ | 24.56 | 2.05 | 19.29 | 1.61 | $5\frac{3}{16}$ | 91.49 | 7.62 | 71.86 | 5.98 |

## Weights of Square and Round Steel Bars—(*Cont.*)

| Size in Inches | Square Bars | | Round Bars | | Size in Inches | Square Bars | | Round Bars | |
|---|---|---|---|---|---|---|---|---|---|
| | Per Foot | Per Inch | Per Foot | Per Inch | | Per Foot | Per Inch | Per Foot | Per Inch |
| $5\frac{1}{4}$ | 93.71 | 7.81 | 73.60 | 6.13 | $8\frac{1}{4}$ | 231.41 | 19.28 | 181.75 | 15.15 |
| $5\frac{5}{16}$ | 95.96 | 8.00 | 75.36 | 6.27 | $8\frac{3}{8}$ | 238.48 | 19.87 | 187.30 | 15.61 |
| $5\frac{3}{8}$ | 98.23 | 8.19 | 77.15 | 6.42 | $8\frac{1}{2}$ | 245.65 | 20.47 | 192.93 | 16.08 |
| $5\frac{7}{16}$ | 100.53 | 8.38 | 78.95 | 6.57 | $8\frac{5}{8}$ | 252.93 | 21.08 | 198.65 | 16.55 |
| $5\frac{1}{2}$ | 102.85 | 8.57 | 80.78 | 6.72 | $8\frac{3}{4}$ | 260.31 | 21.69 | 204.45 | 17.04 |
| $5\frac{9}{16}$ | 105.20 | 8.77 | 82.62 | 6.88 | $8\frac{7}{8}$ | 267.80 | 22.32 | 210.33 | 17.55 |
| $5\frac{5}{8}$ | 107.58 | 8.97 | 84.49 | 7.03 | 9 | 275.40 | 22.95 | 216.30 | 18.03 |
| $5\frac{11}{16}$ | 109.98 | 9.17 | 86.38 | 7.19 | $9\frac{1}{8}$ | 283.10 | 23.59 | 222.35 | 18.53 |
| $5\frac{3}{4}$ | 112.41 | 9.37 | 88.29 | 7.35 | $9\frac{1}{4}$ | 290.91 | 24.24 | 228.48 | 19.04 |
| $5\frac{13}{16}$ | 114.87 | 9.57 | 90.22 | 7.51 | $9\frac{3}{8}$ | 298.83 | 24.90 | 234.70 | 19.56 |
| $5\frac{7}{8}$ | 117.35 | 9.78 | 92.17 | 7.67 | $9\frac{1}{2}$ | 306.85 | 25.57 | 241.00 | 20.08 |
| $5\frac{15}{16}$ | 119.86 | 9.99 | 94.14 | 7.84 | $9\frac{5}{8}$ | 314.98 | 26.25 | 247.38 | 20.62 |
| 6 | 122.40 | 10.20 | 96.13 | 8.00 | $9\frac{3}{4}$ | 323.21 | 26.93 | 253.85 | 21.15 |
| $6\frac{1}{8}$ | 127.55 | 10.63 | 100.18 | 8.34 | $9\frac{7}{8}$ | 331.55 | 27.63 | 260.40 | 21.87 |
| $6\frac{1}{4}$ | 132.81 | 11.07 | 104.31 | 8.68 | 10 | 340.00 | 28.33 | 267.04 | 22.25 |
| $6\frac{3}{8}$ | 138.18 | 11.52 | 108.53 | 9.03 | $10\frac{1}{8}$ | 348.55 | 29.05 | 273.75 | 22.81 |
| $6\frac{1}{2}$ | 143.65 | 11.97 | 112.82 | 9.39 | $10\frac{1}{4}$ | 357.21 | 29.77 | 280.55 | 23.38 |
| $6\frac{5}{8}$ | 149.23 | 12.44 | 117.20 | 9.76 | $10\frac{3}{8}$ | 365.98 | 30.50 | 287.44 | 23.95 |
| $6\frac{3}{4}$ | 154.91 | 12.91 | 121.67 | 10.14 | $10\frac{1}{2}$ | 374.85 | 31.24 | 294.41 | 24.53 |
| $6\frac{7}{8}$ | 160.70 | 13.39 | 126.22 | 10.52 | $10\frac{5}{8}$ | 383.83 | 31.99 | 301.46 | 25.12 |
| 7 | 166.60 | 13.88 | 130.85 | 10.90 | $10\frac{3}{4}$ | 392.91 | 32.74 | 308.59 | 25.72 |
| $7\frac{1}{8}$ | 172.60 | 14.38 | 135.56 | 11.30 | $10\frac{7}{8}$ | 402.10 | 33.51 | 315.81 | 26.32 |
| $7\frac{1}{4}$ | 178.71 | 14.89 | 140.36 | 11.70 | 11 | 411.40 | 34.28 | 323.11 | 26.93 |
| $7\frac{3}{8}$ | 184.93 | 15.41 | 145.24 | 12.10 | $11\frac{1}{8}$ | 420.80 | 35.07 | 330.50 | 27.54 |
| $7\frac{1}{2}$ | 191.25 | 15.94 | 150.21 | 12.52 | $11\frac{1}{4}$ | 430.31 | 35.86 | 337.97 | 28.16 |
| $7\frac{5}{8}$ | 197.68 | 16.47 | 155.26 | 12.94 | $11\frac{3}{8}$ | 439.93 | 36.66 | 345.52 | 28.79 |
| $7\frac{3}{4}$ | 204.21 | 17.02 | 160.39 | 13.37 | $11\frac{1}{2}$ | 449.65 | 37.47 | 353.16 | 29.43 |
| $7\frac{7}{8}$ | 210.85 | 17.57 | 165.60 | 13.80 | $11\frac{5}{8}$ | 459.48 | 38.29 | 360.87 | 30.07 |
| 8 | 217.60 | 18.13 | 170.90 | 14.24 | $11\frac{3}{4}$ | 469.41 | 39.12 | 368.68 | 30.72 |
| $8\frac{1}{8}$ | 224.45 | 18.70 | 176.29 | 14.69 | $11\frac{7}{8}$ | 479.45 | 39.95 | 376.56 | 31.38 |
| | | | | | 12 | 489.60 | 40.80 | 384.53 | 32.04 |

## Strength of Round Steel Bars

Breaking Strength, 51,000 Pounds per Square Inch. Proof Strength, One-half Ultimate Strength. Working Loads Are Percentages of the Proof Strength.

| Diam., Inches | Area, Sq. In. | Breaking Strength, Pounds | Proof Load, in Pounds | Working Load at | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 25% | 30% | 35% | 40% | 45% | 50% |
| $\frac{1}{4}$ | 0.049 | 2,499 | 1,250 | 313 | 375 | 438 | 500 | 563 | 625 |
| $\frac{5}{16}$ | .077 | 3,927 | 1,964 | 491 | 589 | 687 | 785 | 884 | 982 |
| $\frac{3}{8}$ | .110 | 5,610 | 2,805 | 701 | 842 | 982 | 1,122 | 1,262 | 1,403 |
| $\frac{7}{16}$ | .150 | 7,650 | 3,825 | 956 | 1,148 | 1,339 | 1,530 | 1,721 | 1,913 |
| $\frac{1}{2}$ | .196 | 9,996 | 4,998 | 1,250 | 1,499 | 1,749 | 1,999 | 2,249 | 2,499 |

STRENGTH OF ROUND STEEL BARS—(*Cont.*)

| Diam., Inches | Area, Sq. In. | Breaking Strength, Pounds | Proof Load, in Pounds | Working Load at | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 25% | 30% | 35% | 40% | 45% | 50% |
| 9/16 | .249 | 12,699 | 6,350 | 1,588 | 1,905 | 2,223 | 2,540 | 2,858 | 3,175 |
| 5/8 | .307 | 15,657 | 7,829 | 1,957 | 2,349 | 2,740 | 3,131 | 3,523 | 3,914 |
| 11/16 | .371 | 18,921 | 9,460 | 2,365 | 2,838 | 3,311 | 3,784 | 4,257 | 4,730 |
| 3/4 | .442 | 22,542 | 11,271 | 2,818 | 3,381 | 3,945 | 4,508 | 5,072 | 5,636 |
| 13/16 | .519 | 26,469 | 13,235 | 3,309 | 3,970 | 4,632 | 5,294 | 5,956 | 6,617 |
| 7/8 | .601 | 30,651 | 15,326 | 3,832 | 4,598 | 5,364 | 6,130 | 6,897 | 7,663 |
| 15/16 | .690 | 35,190 | 17,595 | 4,399 | 5,279 | 6,158 | 7,038 | 7,918 | 8,798 |
| 1 | .785 | 40,035 | 20,018 | 5,005 | 6,005 | 7,007 | 8,007 | 9,008 | 10,009 |
| 1 1/16 | .887 | 45,237 | 22,619 | 5,655 | 6,786 | 7,917 | 9,048 | 10,179 | 11,310 |
| 1 1/8 | .994 | 50,694 | 25,347 | 6,337 | 7,604 | 8,871 | 10,139 | 11,406 | 12,674 |
| 1 3/16 | 1.108 | 56,508 | 28,254 | 7,064 | 8,476 | 9,889 | 11,302 | 12,714 | 14,127 |
| 1 1/4 | 1.227 | 62,577 | 31,289 | 7,822 | 9,387 | 10,951 | 12,516 | 14,080 | 15,645 |
| 1 5/16 | 1.353 | 69,003 | 34,502 | 8,626 | 10,351 | 12,076 | 13,801 | 15,526 | 17,251 |
| 1 3/8 | 1.485 | 75,735 | 37,868 | 9,467 | 11,360 | 13,254 | 15,148 | 17,041 | 18,934 |
| 1 7/16 | 1.623 | 82,773 | 41,387 | 10,347 | 12,416 | 14,485 | 16,555 | 18,624 | 20,694 |
| 1 1/2 | 1.767 | 90,117 | 45,059 | 11,265 | 13,518 | 15,771 | 18,024 | 20,277 | 22,530 |
| 1 9/16 | 1.918 | 97,818 | 48,909 | 12,227 | 14,673 | 17,118 | 19,564 | 22,009 | 24,455 |
| 1 5/8 | 2.074 | 105,774 | 52,887 | 13,222 | 15,866 | 18,510 | 21,155 | 23,799 | 26,444 |
| 1 11/16 | 2.237 | 114,087 | 57,044 | 14,261 | 17,113 | 19,965 | 22,818 | 25,670 | 28,522 |
| 1 3/4 | 2.405 | 122,655 | 61,328 | 15,332 | 18,398 | 21,465 | 24,531 | 27,598 | 30,664 |
| 1 13/16 | 2.580 | 131,580 | 65,790 | 16,448 | 19,737 | 23,027 | 26,316 | 29,606 | 32,895 |
| 1 7/8 | 2.761 | 140,811 | 70,406 | 17,602 | 21,122 | 24,642 | 28,162 | 31,683 | 35,203 |
| 1 15/16 | 2.948 | 150,348 | 75,174 | 18,794 | 22,552 | 26,311 | 30,070 | 33,828 | 37,587 |
| 2 | 3.142 | 160,242 | 80,121 | 20,030 | 24,036 | 28,042 | 32,048 | 36,054 | 40,061 |
| 2 1/16 | 3.341 | 170,391 | 85,196 | 21,299 | 25,559 | 29,819 | 34,078 | 38,338 | 42,598 |
| 2 1/8 | 3.547 | 180,897 | 90,449 | 22,612 | 27,135 | 31,657 | 36,180 | 40,702 | 45,225 |
| 2 3/16 | 3.758 | 191,658 | 95,829 | 23,957 | 28,749 | 33,540 | 38,332 | 43,123 | 47,915 |
| 2 1/4 | 3.976 | 202,776 | 101,388 | 25,347 | 30,416 | 35,486 | 40,555 | 45,625 | 50,694 |
| 2 5/16 | 4.200 | 214,200 | 107,100 | 26,775 | 32,130 | 37,485 | 42,840 | 48,195 | 53,550 |
| 2 3/8 | 4.430 | 225,930 | 112,965 | 28,241 | 33,890 | 39,538 | 45,186 | 50,834 | 56,483 |
| 2 7/16 | 4.666 | 237,966 | 118,983 | 29,746 | 35,695 | 41,644 | 47,593 | 53,542 | 59,492 |
| 2 1/2 | 4.909 | 250,359 | 125,180 | 31,295 | 37,554 | 43,813 | 50,072 | 56,331 | 62,590 |
| 2 9/16 | 5.157 | 263,007 | 131,504 | 32,876 | 39,451 | 46,026 | 52,602 | 59,177 | 65,752 |
| 2 5/8 | 5.412 | 276,012 | 138,006 | 34,502 | 41,402 | 48,302 | 55,202 | 62,103 | 69,003 |
| 2 11/16 | 5.673 | 289,323 | 144,662 | 36,166 | 43,399 | 50,632 | 57,865 | 65,098 | 72,331 |
| 2 3/4 | 5.940 | 302,940 | 151,470 | 37,868 | 45,441 | 53,015 | 60,588 | 68,162 | 75,735 |
| 2 13/16 | 6.213 | 316,863 | 158,432 | 39,608 | 47,530 | 55,451 | 63,373 | 71,294 | 79,216 |
| 2 7/8 | 6.492 | 331,092 | 165,546 | 41,387 | 49,664 | 57,941 | 66,218 | 74,496 | 82,773 |
| 2 15/16 | 6.777 | 345,627 | 172,814 | 43,204 | 51,844 | 60,485 | 69,126 | 77,766 | 86,407 |
| 3 | 7.069 | 360,519 | 180,260 | 45,065 | 54,078 | 63,091 | 72,104 | 81,117 | 90,130 |
| 3 1/16 | 7.366 | 375,666 | 187,833 | 46,958 | 56,350 | 65,742 | 75,133 | 84,525 | 93,917 |
| 3 1/8 | 7.670 | 391,170 | 195,585 | 48,896 | 58,676 | 68,455 | 78,234 | 88,013 | 97,793 |
| 3 3/16 | 7.980 | 401,880 | 200,940 | 50,235 | 60,282 | 70,329 | 80,376 | 90,423 | 100,470 |
| 3 1/4 | 8.296 | 423,096 | 211,548 | 52,887 | 63,464 | 74,042 | 84,619 | 95,197 | 105,774 |
| 3 5/16 | 8.618 | 439,518 | 219,759 | 54,940 | 65,928 | 76,916 | 87,904 | 98,892 | 109,880 |

STRENGTH OF ROUND STEEL BARS—(*Cont.*)

| Diam., Inches | Area, Sq. In. | Breaking Strength, Pounds | Proof Load in Pounds | Working Load at 25% | 30% | 35% | 40% | 45% | 50% |
|---|---|---|---|---|---|---|---|---|---|
| $3\frac{3}{8}$ | 8.946 | 456,246 | 228,123 | 57,031 | 68,437 | 79,843 | 91,249 | 102,655 | 114,062 |
| $3\frac{7}{16}$ | 9.281 | 473,331 | 236,666 | 59,167 | 71,000 | 82,833 | 94,666 | 106,500 | 118,333 |
| $3\frac{1}{2}$ | 9.621 | 490,671 | 245,336 | 61,334 | 73,601 | 85,868 | 98,134 | 110,401 | 122,668 |
| $3\frac{9}{16}$ | 9.968 | 508,368 | 254,184 | 63,546 | 76,255 | 88,964 | 101,674 | 114,383 | 127,092 |
| $3\frac{5}{8}$ | 10.321 | 526,371 | 263,186 | 65,797 | 78,956 | 92,115 | 105,274 | 118,434 | 131,593 |
| $3\frac{11}{16}$ | 10.680 | 544,680 | 272,340 | 68,085 | 81,702 | 95,319 | 108,936 | 122,553 | 136,170 |
| $3\frac{3}{4}$ | 11.045 | 563,295 | 281,648 | 70,412 | 84,494 | 98,577 | 112,659 | 126,742 | 140,824 |
| $3\frac{13}{16}$ | 11.416 | 582,216 | 291,108 | 72,777 | 87,332 | 101,888 | 116,443 | 130,999 | 145,554 |
| $3\frac{7}{8}$ | 11.793 | 601,443 | 300,722 | 75,181 | 90,217 | 105,253 | 120,289 | 135,325 | 150,361 |
| $3\frac{15}{16}$ | 12.177 | 621,027 | 310,514 | 77,629 | 93,154 | 108,680 | 124,206 | 139,731 | 155,257 |
| 4 | 12.566 | 640,866 | 320,433 | 80,108 | 96,130 | 112,152 | 128,173 | 144,195 | 160,217 |

# STEEL HULL RIVETS AND RIVET-RODS

## NAVY DEPARTMENT

1. **General Instructions.**—The latest issue of "General Specifications for Inspection of Steel and Iron Material" shall form a part of these specifications, and must be complied with as to material, methods of inspection, and all other requirements therein.

2. **Physical and Chemical Requirements.**—The physical and chemical requirements for each grade of material shall be in accordance with the following table:

| Grade | Material | Tensile Strength, Pounds per Square Inch | Minimum Elongation (b) | Maximum Amount of— P. | S. |
|---|---|---|---|---|---|
| | | | | *P. Ct.* | *P. Ct.* |
| Medium steel | Open-hearth carbon. | 58,000 to 68,000 | 28 per cent in 8 inches; 30 per cent in 2 inches when type 1 specimen is used. | 0.04 | 0.04 |
| High-tensile steel. | Open-hearth carbon, silicon, or nickel steel. | 75,000 to 90,000 | 23 per cent in 8 inches; 25 per cent in 2 inches when type 1 specimen is used. | .04 | .04 |

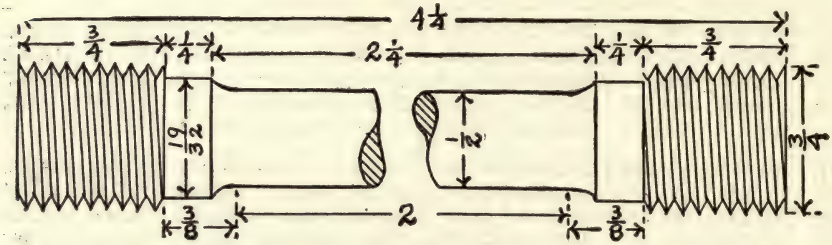
### RIVET RODS

3. **Elongation.**—For rods $\frac{1}{2}$ inch or less in thickness or diameter, the elongation shall be measured on a length equal to eight times the thickness or diameter of section tested; for sections over $\frac{1}{2}$ inch and less than $\frac{3}{4}$ inch in thickness or diameter, the elongation shall be taken on a leng h of 6 inches. In both the preceding cases the required percentage of elongation shall be that specified for the type 3 test piece.

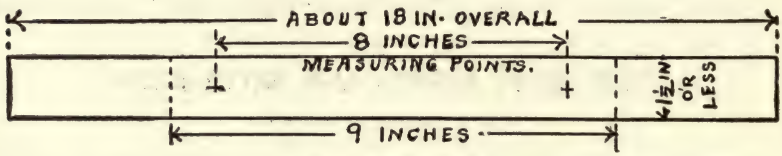
4. **Type of Test Piece.**—Type of test piece to be type 1 or type 3, depending on size of rod; type 1 will be used only when capacity of testing machine prevents the use of type 3.

5. **Tensile Tests.**—Bars rolled from any melt shall be tested by sizes, one tensile test to be taken from each ton or less of each size. If the results of such tests from the various sizes indicate that the material is of uniform quality, not more than eight such specimens shall be taken to represent the melt. In such cases the eight specimens shall be fully representative of the various sizes in the melt offered for test.

6. **Bending Tests for Medium Steel.**—From each size of each melt one cold-bend test shall be taken as finished in the rolls, but not less than two such bends shall be made from any melt. These cold-bend specimens shall be bent 180° flat on themselves without showing any cracks or flaws in the outer round.




TYPE 1 TEST PIECE




TYPE 3 TEST PIECE

7. **Upsetting Tests for Medium Steel.**—Specimens shall be cut about one and one-fourth times the diameter of the round in length, and shall be required to stand hammering down cold in a longitudinal direction to about one-half the original length of the specimen without showing seams or other defects which would, in the judgment of the inspector, tend to produce defects in the manufactured rivet.

The number of upsetting-test pieces shall equal the number of tensile-test pieces, but in no case shall it be less than two for each size.

8. **Tolerances in Diameter Under the Nominal Gauge Ordered.**—

| | |
|---|---|
| Up to and including ¼ inch | 0.010 inch. |
| Over ¼ inch, up to and including ½ inch | .014 inch. |
| Over ½ inch, up to and including ¾ inch | .016 inch. |
| Over ¾ inch, up to and including 1 inch | .020 inch. |
| Over 1 inch, up to and including 1¼ inches | .024 inch. |
| Over 1¼ inches | .030 inch. |

## MANUFACTURED RIVETS

9. **Manufactured Rivets, Form and Surfaces.**—(a) Rivets shall be true to form, concentric, and free from scale, fins, seams, and all other injurious or unsightly defects. Tap rivets shall be milled under the head if necessary. They shall conform to the dimensions and form as shown on table incorporated in and forming a part of these specifications.

10. **Medium Steel Rivets, Hammer Tests.**—(a) From each lot of rivets of each size kegged and ready for shipment there shall be taken at random 6 rivets, to be tested as follows:

(b) Three rivets shall be flattened out cold under the hammer to a thickness of one-half the diameter of the part flattened without showing cracks or flaws. Rivets of over an inch in diameter shall be flattened to three-fourths of the original diameter.

(c) Three rivets shall be flattened out hot under hammer to a thickness not exceeding one-fourth of the original diameter of part flattened without showing cracks; heat to be ordinary driving heat.

11. **High-Tensile Steel Rivets.**—High-tensile steel rivets shall be made of rivet rods

conforming to the requirements of these specifications for high-tensile steel rods and shall in addition meet the following requirements:

12. **Shearing Strength.**—From each lot of each size kegged and ready for shipment there shall be taken at random three rivets for shearing test. These rivets shall be driven hot for test under double shear. The shearing strength when so tested shall not be less than 64,000 pounds per square inch, computed on the actual shearing area of the rivet as driven; i.e., the area corresponding to the area of the rivet hole, not the nominal diameter of the rivet.

13. **Quality Test.**—When for any reason the shearing test described above cannot be made, the following test shall be made: From each lot of each size kegged ready for shipment there shall be taken at randon three rivets. These rivets shall be heated to the driving temperature, when the point shall be quickly hammered down to a thickness of ⅛ inch and the rivet immediately cooled by quenching in cold water. It will then be hammered over the edge of an anvil in an effort to bend the flattened portion. The rivet shall break short without appreciable bend.

14. **Marking and Packing.**—(a) Medium rivets shall be marked on top or side of head with a plain cross ⅜ by ⅜ inch for larger sized rivets, suitably reduced for the smaller rivets. This cross is to be in relief.

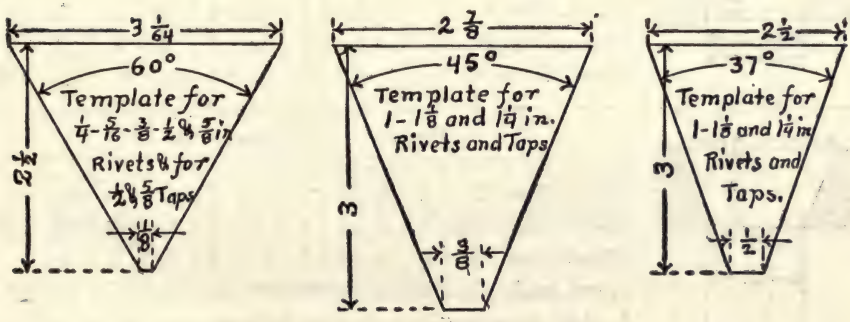
(b) High-tensile pan or button-head rivets shall have fluted heads.

(c) Unless otherwise specified, to be delivered in 100-pound boxes or kegs, marked as given below.

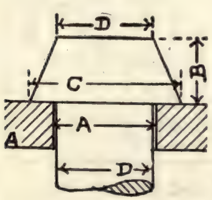
(d) All boxes or kegs to be strongly made and plainly marked with the manufacturer's name and contract number.

Boxes or kegs to be neatly stenciled on one end only with the net weight, size, and name of contents, as—

100 pounds
½" x 1½"
High-Tensile Steel
Button-Head Rivets.



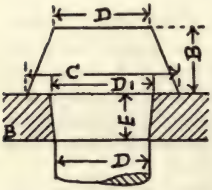

STANDARD RIVETS FOR SHIP AND TORPEDO-BOAT WORK. NAVY DEPARTMENT




Type A. Pan Head. Straight Neck

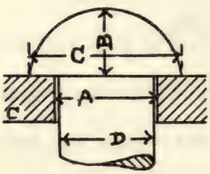
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Rivet, Diam. D.. | ¼ | 5/16 | ⅜ | ½ | ⅝ | ¾ | ⅞ | 1 | 1⅛ | 1¼ |
| Hole, Diam. A... | 9/32 | 23/64 | 7/16 | 9/16 | 11/16 | 13/16 | 15/16 | 1 1/16 | 1 7/32 | 1 11/32 |
| Head, High B... | 3/16 | ¼ | 5/16 | ⅜ | 7/16 | ½ | 9/16 | ⅝ | 11/16 | ¾ |
| Head, Diam. C.. | 7/16 | ½ | 9/16 | 13/16 | 1 | 1 3/16 | 1 5/16 | 1½ | 1⅝ | 1 13/16 |
| Head, Diam D... | ¼ | 5/16 | ⅜ | ½ | ⅝ | ¾ | ⅞ | 1 | 1⅛ | 1¼ |

## Standard Rivets for Ship and Torpedo-Boat Work. Navy Department
*(Continued)*



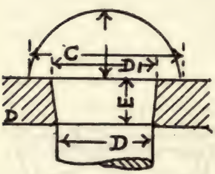

### Type B. Pan Head. Conical Neck

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Rivet, Diam. D.. | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{7}{8}$ | 1 | $1\frac{1}{8}$ | $1\frac{1}{4}$ |
| Neck, Diam. D1. | .. | .. | .. | $\frac{9}{16}$ | $\frac{11}{16}$ | $\frac{13}{16}$ | $\frac{15}{16}$ | $1\frac{1}{16}$ | $1\frac{3}{16}$ | $1\frac{5}{16}$ |
| Neck, Cone E... | .. | .. | .. | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{9}{16}$ | $\frac{7}{8}$ |
| Head, High B... | .. | .. | .. | $\frac{3}{8}$ | $\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{9}{16}$ | $\frac{5}{8}$ | $\frac{11}{16}$ | $\frac{3}{4}$ |
| Head, Diam. C.. | .. | .. | .. | $\frac{13}{16}$ | 1 | $1\frac{3}{16}$ | $1\frac{5}{16}$ | $1\frac{1}{2}$ | $1\frac{5}{8}$ | $1\frac{13}{16}$ |
| Head, Diam. D.. | .. | .. | .. | $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{7}{8}$ | 1 | $1\frac{1}{8}$ | $1\frac{1}{4}$ |



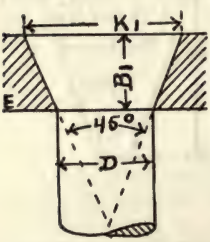

### Type C. Button Head. Straight Neck

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Rivet, Diam. D.. | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{7}{8}$ | 1 | $1\frac{1}{8}$ | $1\frac{1}{4}$ |
| Hole, Diam. A... | $\frac{9}{32}$ | $\frac{23}{64}$ | $\frac{7}{16}$ | $\frac{9}{16}$ | $\frac{11}{16}$ | $\frac{13}{16}$ | $\frac{15}{16}$ | $1\frac{1}{16}$ | $1\frac{7}{32}$ | $1\frac{11}{32}$ |
| Head, High B... | $\frac{3}{16}$ | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{9}{16}$ | $\frac{5}{8}$ | $\frac{11}{16}$ | $\frac{3}{4}$ |
| Head, Diam. C.. | $\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{9}{16}$ | $\frac{13}{16}$ | 1 | $1\frac{3}{16}$ | $1\frac{5}{16}$ | $1\frac{1}{2}$ | $1\frac{5}{8}$ | $1\frac{13}{16}$ |




### Type D. Button Head. Conical Neck

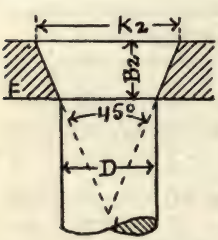
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Rivet, Diam. D. | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{7}{8}$ | 1 | $1\frac{1}{8}$ | $1\frac{1}{4}$ |
| Neck, Diam. D1. | .. | .. | .. | $\frac{9}{16}$ | $\frac{11}{16}$ | $\frac{13}{16}$ | $\frac{15}{16}$ | $1\frac{1}{16}$ | $1\frac{3}{16}$ | $1\frac{5}{16}$ |
| Neck, Cone E... | .. | .. | .. | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{9}{16}$ | $\frac{5}{8}$ |
| Head, High B... | .. | .. | .. | $\frac{3}{8}$ | $\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{9}{16}$ | $\frac{5}{8}$ | $\frac{11}{16}$ | $\frac{3}{4}$ |
| Head, Diam. C.. | .. | .. | .. | $\frac{13}{16}$ | 1 | $1\frac{3}{16}$ | $1\frac{5}{16}$ | $1\frac{1}{2}$ | $1\frac{5}{8}$ | $1\frac{13}{16}$ |




### Type E. Countersunk Head

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Rivet, Diam. D.. | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{7}{8}$ | 1 | $1\frac{1}{8}$ | $1\frac{1}{4}$ |
| Head, Diam. K1. | $\frac{3}{8}$ | $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{7}{8}$ | $1\frac{1}{16}$ | $1\frac{7}{32}$ | $1\frac{1}{2}$ | $1\frac{19}{32}$ | $1\frac{23}{32}$ | $1\frac{29}{32}$ |
| Head, Cone B1.. | $\frac{3}{32}$ | $\frac{5}{32}$ | $\frac{7}{32}$ | $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{9}{16}$ | $\frac{3}{4}$ | $\frac{7}{8}$ | $\frac{7}{8}$ | 1 |
| Cone Angle..... | 60° | 60° | 60° | 60° | 60° | 45° | 45° | 37° | 37° | 37° |

The cone angle of 45° in sketch is for $\frac{3}{4}$ and $\frac{7}{8}$ rivets only.

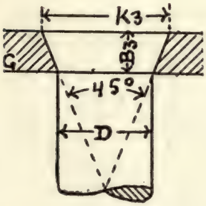



### Type F. Countersunk Head

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Rivet, Diam. D.. | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{7}{8}$ | 1 | $1\frac{1}{8}$ | $1\frac{1}{4}$ |
| Head, Diam. K2 | .. | .. | .. | .. | $\frac{15}{16}$ | $1\frac{1}{8}$ | $1\frac{11}{32}$ | $1\frac{1}{2}$ | ... | ... |
| Head, Cone B2.. | .. | .. | .. | .. | $\frac{9}{32}$ | $\frac{7}{16}$ | $\frac{9}{16}$ | $\frac{3}{4}$ | ... | ... |
| Cone Angle..... | .. | .. | .. | .. | 60° | 45° | 45° | 37° | ... | ... |

The cone angle of 45° in sketch is for $\frac{3}{4}$ and $\frac{7}{8}$ rivets only.

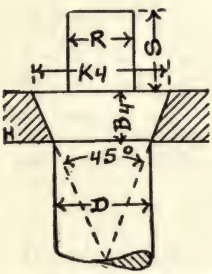
Standard Rivets for Ship and Torpedo-Boat Work. Navy Department
(*Continued*)




**Type G. Countersunk Head**

| Rivet, Diam D.. | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{7}{8}$ | 1 | $1\frac{1}{8}$ | $1\frac{1}{4}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Head, Diam K3 | .. | .. | .. | .. | .. | 1 | $1\frac{1}{4}$ | ... | $1\frac{9}{16}$ | ... |
| Head, Cone B3.. | .. | .. | .. | .. | .. | $\frac{5}{16}$ | $\frac{7}{16}$ | ... | $\frac{5}{8}$ | ... |
| Cone Angle..... | .. | .. | .. | .. | .. | 45° | 45° | ... | 37° | ... |

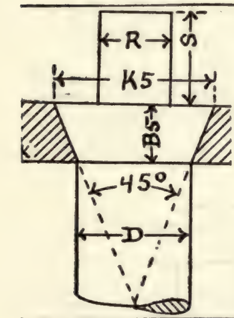
The cone angle of 45° in sketch is for $\frac{3}{4}$ and $\frac{7}{8}$ rivets only.




**Type H. Tap Rivets**

| Rivet, Diam. D.. | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{7}{8}$ | 1 | $1\frac{1}{8}$ | $1\frac{1}{4}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Head Diam. K4. | .. | .. | .. | $\frac{23}{32}$ | $\frac{29}{32}$ | $1\frac{1}{16}$ | $1\frac{11}{32}$ | $1\frac{15}{32}$ | $1\frac{23}{32}$ | $1\frac{27}{32}$ |
| Head, Cone B4.. | .. | .. | .. | $\frac{3}{16}$ | $\frac{1}{4}$ | $\frac{3}{8}$ | $\frac{9}{16}$ | $\frac{11}{16}$ | $\frac{7}{8}$ | $\frac{7}{8}$ |
| Cone Angle..... | .. | .. | .. | 60° | 60° | 45° | 45° | 37° | 37° | 37° |
| Stud, Square R.. | .. | .. | .. | $\frac{3}{8}$ | $\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{9}{16}$ | $\frac{5}{8}$ | $\frac{5}{8}$ | $\frac{11}{16}$ |
| Stud, Height S.. | .. | .. | .. | $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{5}{8}$ | $\frac{23}{32}$ | $\frac{23}{32}$ | $\frac{23}{32}$ | $\frac{23}{32}$ |

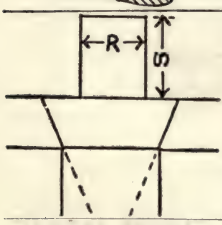
The cone angle of 45° in sketch is for $\frac{3}{4}$ and $\frac{7}{8}$ rivets only.




**Type K. Tap Rivets**

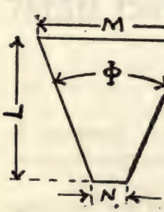
| Rivet, Diam. D . | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{7}{8}$ | 1 | $1\frac{1}{8}$ | $1\frac{1}{4}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Head, Diam. K5 | .. | .. | .. | .. | .. | ... | $1\frac{1}{4}$ | $1\frac{3}{8}$ | $1\frac{5}{8}$ | ... |
| Head, Cone B5.. | .. | .. | .. | .. | .. | ... | $\frac{7}{16}$ | $\frac{9}{16}$ | $\frac{3}{4}$ | ... |
| Cone Angle..... | .. | .. | .. | .. | .. | ... | 45° | 37° | 37° | ... |
| Stud, Square R.. | .. | .. | .. | .. | .. | ... | $\frac{9}{16}$ | $\frac{5}{8}$ | $\frac{5}{8}$ | ... |
| Stud, Height S... | .. | .. | .. | .. | .. | ... | $\frac{23}{32}$ | $\frac{23}{32}$ | $\frac{23}{32}$ | ... |

The cone angle of 45° in sketch is for $\frac{7}{8}$ rivets only.




**Studs for Tap Rivets**

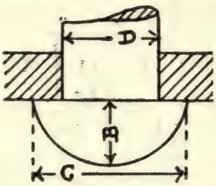
| Rivet, Diam..... | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{7}{8}$ | 1 | $1\frac{1}{8}$ | $1\frac{1}{4}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Stud, Square R.. | .. | .. | .. | $\frac{3}{8}$ | $\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{9}{16}$ | $\frac{5}{8}$ | $\frac{5}{8}$ | $\frac{11}{16}$ |
| Stud, Height S... | .. | .. | .. | $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{23}{32}$ | $\frac{23}{32}$ | $\frac{23}{32}$ | $\frac{23}{32}$ | $\frac{23}{32}$ |




**Template for Countersink**

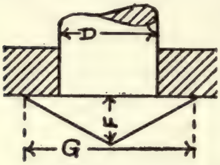
| Rivet, Diam.... | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{7}{8}$ | 1 | $1\frac{1}{8}$ | $1\frac{1}{4}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Angle $\Phi$........ | 60° | 60° | 60° | 60° | 60° | 45° | 45° | 37° | 37° | 37° |
| Height L........ | $2\frac{1}{2}$ | $2\frac{1}{2}$ | $2\frac{1}{2}$ | $2\frac{1}{2}$ | $2\frac{1}{2}$ | 3 | 3 | 3 | 3 | 3 |
| Width M........ | $3\frac{1}{64}$ | $3\frac{1}{64}$ | $3\frac{1}{64}$ | $3\frac{1}{64}$ | $3\frac{1}{64}$ | $2\frac{7}{8}$ | $2\frac{7}{8}$ | $2\frac{1}{2}$ | $2\frac{1}{2}$ | $2\frac{1}{2}$ |
| Width N........ | $\frac{1}{8}$ | $\frac{1}{8}$ | $\frac{1}{8}$ | $\frac{1}{8}$ | $\frac{1}{8}$ | $\frac{3}{8}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{1}{2}$ |

STANDARD RIVETS FOR SHIP AND TORPEDO-BOAT WORK. NAVY DEPARTMENT
(*Continued*)




Snap Points

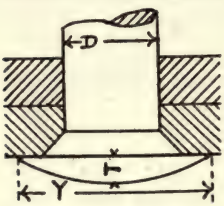
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Rivet, Diam. D.. | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{7}{8}$ | 1 | $1\frac{1}{8}$ | $1\frac{1}{4}$ |
| Point, Height B. | $\frac{3}{16}$ | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{9}{16}$ | $\frac{5}{8}$ | $\frac{11}{16}$ | $\frac{3}{4}$ |
| Point, Diam. C.. | $\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{9}{16}$ | $\frac{13}{16}$ | 1 | $1\frac{3}{16}$ | $1\frac{5}{16}$ | $1\frac{1}{2}$ | $1\frac{5}{8}$ | $1\frac{13}{16}$ |




Hammered Points. $F-\frac{1}{2}D$

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Rivet, Diam. D.. | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{7}{8}$ | 1 | $1\frac{1}{8}$ | $1\frac{1}{4}$ |
| Point, Height F. | $\frac{1}{8}$ | $\frac{5}{32}$ | $\frac{3}{16}$ | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{9}{16}$ | $\frac{5}{8}$ |
| Point, Diam. G.. | $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | 1 | $1\frac{1}{8}$ | $1\frac{5}{16}$ | $1\frac{1}{2}$ | $1\frac{3}{4}$ | $1\frac{15}{16}$ | $2\frac{1}{8}$ |

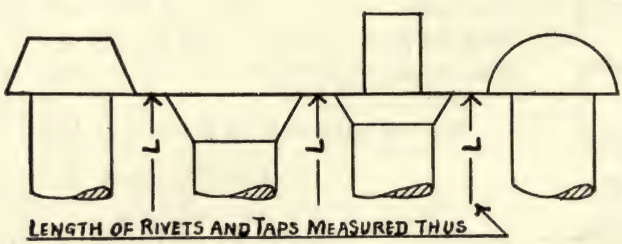
Countersunk points to be the same taper and depth as countersunk heads, but are to be driven with slightly convex tops.




Liverpool Points. $Y-2D$

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Rivet, Diam. D.. | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{7}{8}$ | 1 | $1\frac{1}{8}$ | $1\frac{1}{4}$ |
| Point, Height T. | .. | .. | .. | $\frac{1}{8}$ | $\frac{1}{8}$ | $\frac{3}{16}$ | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{3}{8}$ | ... |
| Point, Diam. Y. | .. | .. | .. | 1 | $1\frac{1}{4}$ | $1\frac{1}{2}$ | $1\frac{3}{4}$ | 2 | $2\frac{1}{4}$ | ... |

Countersunk Liverpool points to be the same taper as countersunk heads, but to be only one-half the thickness of plate.




## SMALL RIVETS, FLAT OR COUNTERSUNK, FOR SHEET-METAL WORK

### NAVY DEPARTMENT

1. "General Instructions and Specifications, General Specifications, Appendix I, for Iron and Steel Material," issued June, 1912, shall form a part of these specifications and must be complied with.

2. To be soft steel, black or tinned, as specified. The flat-head rivets shall conform in size and weight to the following table:

| Size | Limit | Size of Wire | Length Under Head | Diameter of Head | Thickness of Head |
|---|---|---|---|---|---|
| 4 ounces | 0.072 | 0.068 | $\frac{1}{8}$ | 0.156 | 0.020 |
| 6 ounces | .083 | .078 | $\frac{9}{64}$ | .180 | .024 |
| 8 ounces | .095 | .090 | $\frac{5}{32}$ | .206 | .027 |
| 10 ounces | .090 | .094 | $\frac{11}{64}$ | .214 | .029 |
| 12 ounces | .106 | .100 | $\frac{3}{16}$ | .230 | .031 |
| 14 ounces | .110 | .104 | $\frac{3}{16}$ | .239 | .032 |
| 1 pound | .115 | .109 | $\frac{13}{64}$ | .249 | .033 |
| $1\frac{1}{4}$ pounds | .120 | .113 | $\frac{7}{32}$ | .260 | .034 |
| $1\frac{1}{2}$ pounds | .126 | .120 | $\frac{15}{64}$ | .273 | .036 |
| $1\frac{3}{4}$ pounds | .134 | .128 | $\frac{1}{4}$ | .290 | .038 |
| 2 pounds | .144 | .136 | $\frac{17}{64}$ | .312 | .041 |
| $2\frac{1}{2}$ pounds | .148 | .141 | $\frac{9}{32}$ | .323 | .043 |
| 3 pounds | .160 | .151 | $\frac{5}{16}$ | .346 | .046 |
| $3\frac{1}{2}$ pounds | .165 | .156 | $\frac{21}{64}$ | .357 | .047 |
| 4 pounds | .176 | .167 | $\frac{11}{32}$ | .381 | .050 |
| 5 pounds | .189 | .180 | $\frac{3}{8}$ | .409 | .054 |
| 6 pounds | .205 | .195 | $\frac{25}{64}$ | .444 | .058 |
| 7 pounds | .221 | .211 | $\frac{13}{32}$ | .479 | .063 |
| 8 pounds | .229 | .219 | $\frac{7}{16}$ | .496 | .065 |
| 9 pounds | .238 | .227 | $\frac{29}{64}$ | .515 | .068 |
| 10 pounds | .241 | .230 | $\frac{15}{32}$ | .522 | .070 |
| 12 pounds | .254 | .242 | $\frac{1}{2}$ | .550 | .074 |
| 14 pounds | .284 | .272 | $\frac{33}{64}$ | .616 | .081 |
| 16 pounds | .300 | .288 | $\frac{17}{32}$ | .650 | .086 |

3. The countersunk rivets shall conform to the sizes given in the following table:

| Size of Rivet, Diameter of Wire | Diameter of Head | Angle of Countersink | Lengths | Size of Rivet, Diameter of Wire | Diameter of Head | Angle of Countersink | Lengths |
|---|---|---|---|---|---|---|---|
| *Inch* | *Inch* | *Degrees* | *Inch* | *Inch* | *Inch* | *Degrees* | *Inch* |
| $\frac{3}{16}$ 0.189 | 0.345 | 80 | $\frac{3}{8}$ and $\frac{1}{2}$ | $\frac{9}{64}$ .144 | .259 | 80 | $\frac{1}{4}$, $\frac{3}{8}$, and $\frac{1}{2}$ |
| $\frac{5}{32}$ .160 | .287 | 80 | $\frac{1}{4}$, $\frac{3}{8}$, and $\frac{1}{2}$ | $\frac{1}{8}$ .125 | .230 | 80 | $\frac{3}{16}$, $\frac{1}{4}$, and $\frac{5}{16}$ |

4. The rivets to be put up in packages of 1,000 rivets, or in boxes of not less than 50 pounds each, as required.

## TESTS FOR SOFT-STEEL RIVETS

5. A number of rivets, at the discretion of the inspector, shall be selected from each size of each delivery, enough to satisfy the inspector of the quality of the entire lot.

6. **Cold Test.**—One-half of these shall be flattened to one-eighth of their original diameter, and then bent through 180° flat on themselves, and shall show no signs of cracks, flaws, or any other defects.

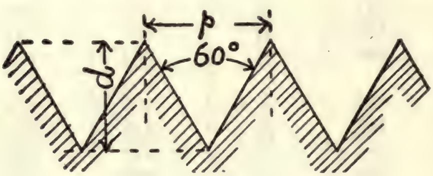
7. **Hot Test.**—The remaining rivets shall be heated to a red heat and flattened, then reheated and bent through 180° and flattened on themselves without showing any signs of flaws, cracks, or any other defects.

# SCREW THREADS

Previous to the action of the Franklin Institute in 1864 there had been no uniformity in the diameters of taps and dies or in the number of threads per inch, for bolts and studs. Bolt iron was seldom rolled strictly to gauge; in consequence, taps and dies $\frac{1}{32}$ inch over size were in general use.

Aside from variation in diameter, there was a lack of uniformity in number of threads per inch. The shape of screw threads then in use was the sharp or V-thread as in the illustration.

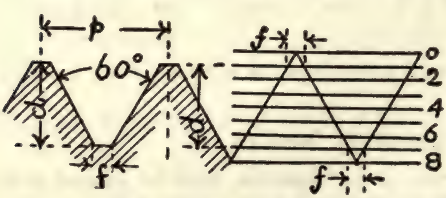
Screw threads with sharp edges are objected to because the threads are liable to injury in the ordinary course of handling. The sharp edges of taps and dies soon disappear in service, making it difficult to maintain interchangeable work.




$$\text{Formula}\begin{cases} p = \text{pitch} = \dfrac{1}{\text{No. thrds. per in.}} \\ d = \text{depth} = p \times .866 \end{cases}$$

An occasional American manufacturer adopted the Whitworth standard for screw threads, but this was exceptional. An investigation of the whole subject was made by William Sellers, of Philadelphia, and presented to the Franklin Institute in a paper read by him in April, 1864. Mr. Sellers disapproved the V-thread; his objections to the Whitworth thread were, first, that the angle of 55° is a difficult one to verify; secondly, the curve at the top and bottom of the thread of the screw will not fit the corresponding curve in the nut, and the wearing surface on the thread will be thus reduced to the straight sides merely. Thirdly, the increased cost and complication of cutting tools required to form this kind of thread in a lathe.

The necessity of guarding the sharp edge of a V-thread from accidental injury was a fact recognized by sometimes finishing such bolts with a small flat on the top of the thread. The flat angular sides being necessary, there remained to choose between a rounded or a flat top. As the sides of a thread are the only parts to be fitted, the cutting tool employed having an angle of 60°, the width of flat at top of thread will be determined by the depth to which the thread is cut. The flat at the top of the thread serves to




$$\text{Formula}\begin{cases} p = \text{pitch} = \dfrac{1}{\text{No. thrds. per in}} \\ d = \text{depth} = p \times .6495 \\ f = \text{flat} = \dfrac{p}{8} \end{cases}$$

protect it from injury, a similar shape at the bottom gives increased strength to the bolt by increasing its diameter at the root of thread.

The angle of thread is 60°, the same as the sharp thread, it being more easily obtained than 55°. Divide the pitch, or, which is the same thing, the side of the thread, into eight equal parts, take off one part from the top and fill in one part in the bottom of the thread, then the flat top and bottom will equal one-eighth of the pitch, the wearing

surface will be three-quarters of the pitch, and the diameter of the screw at bottom of the thread will be expressed by the formula diameter $= \frac{1.299}{\text{No. threads per inch}}$. These proportions will give the depth of the thread almost precisely the same as the English, and as the wearing surface on all screws will be confined practically to the flat sides, this will be 36 per cent greater than on the English.

Franklin Institute Standard Screw Thread

Constants for finding diameter at bottom of thread

Sellers' formula: Diam. bolt $= \frac{1.299}{\text{No. threads per inch}}$

| Threads per Inch | Constant | Threads per Inch | Constant | Threads per Inch | Constant | Threads per Inch | Constant |
|---|---|---|---|---|---|---|---|
| 20 | .06495 | 10 | .12990 | $4\frac{1}{2}$ | .28867 | $2\frac{5}{8}$ | .49486 |
| 18 | .07217 | 9 | .14433 | 4 | .32475 | $2\frac{1}{2}$ | .51960 |
| 16 | .08119 | 8 | .16238 | $3\frac{1}{2}$ | .37114 | $2\frac{3}{8}$ | .54695 |
| 14 | .09279 | 7 | .18557 | $3\frac{1}{4}$ | .39969 | $2\frac{1}{4}$ | .57733 |
| 13 | .09992 | 6 | .21650 | 3 | .43300 | .. | ...... |
| 12 | .10825 | $5\frac{1}{2}$ | .23618 | $2\frac{7}{8}$ | .45183 | .. | ...... |
| 11 | .11809 | 5 | .25980 | $2\frac{3}{4}$ | .47236 | .. | ...... |

Example. To find the diameter at bottom of a Franklin Institute thread for a bolt $1\frac{1}{2}$ inches diameter we have: $1\frac{1}{2}$ inch diameter = 6 threads per inch. The constant for 6 threads is .21650.

Then: $1.50000 - .21650 = 1.2835 = 1\frac{9}{32}$ inch nearly.

Mr. Sellers also presented a system of uniform dimensions for bolt heads and nuts.

The committee of the Institute to whom this paper was referred handed in their final report December 15, 1864, and offered in part the following resolution, which was adopted.

"Resolved, That the Franklin Institute of the State of Pennsylvania recommend, for the general adoption by American engineers, the following forms and proportions for screw threads, bolt heads, and nuts, viz.:

"That screw threads shall be formed with straight sides at an angle to each other of 60°, having a flat surface at the top and bottom equal to one-eighth of the pitch. The pitches shall be as follows, viz.:

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Diameter of bolt.... | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{9}{16}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{7}{8}$ | 1 | $1\frac{1}{8}$ | $1\frac{1}{4}$ | $1\frac{3}{8}$ | $1\frac{1}{2}$ | $1\frac{5}{8}$ | $1\frac{3}{4}$ | $1\frac{7}{8}$ |
| Threads per inch... | 20 | 18 | 16 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 7 | 6 | 6 | $5\frac{1}{2}$ | 5 | 5 |
| Diameter of bolt.... | 2 | $2\frac{1}{4}$ | $2\frac{1}{2}$ | $2\frac{3}{4}$ | 3 | $3\frac{1}{4}$ | $3\frac{1}{2}$ | $3\frac{3}{4}$ | 4 | $4\frac{1}{4}$ | $4\frac{1}{2}$ | $4\frac{3}{4}$ | 5 | $5\frac{1}{4}$ | $5\frac{1}{2}$ | $5\frac{3}{4}$ | 6 |
| Threads per inch... | $4\frac{1}{2}$ | $4\frac{1}{2}$ | 4 | 4 | $3\frac{1}{2}$ | $3\frac{1}{2}$ | $3\frac{1}{4}$ | 3 | 3 | $2\frac{7}{8}$ | $2\frac{3}{4}$ | $2\frac{5}{8}$ | $2\frac{1}{2}$ | $2\frac{1}{2}$ | $2\frac{3}{8}$ | $2\frac{3}{8}$ | $2\frac{1}{4}$ |

"**Bolt Head and Nut.** The distance between the parallel sides of a bolt head and nut, for a rough bolt, shall be equal to one and a half diameters of the bolt plus one-eighth of an inch. The thickness of the heads for a rough bolt shall be equal to one-half the distance between its parallel sides. The thickness of the nut shall be equal to the diameter of the bolt. The thickness of the head for a finished bolt shall be equal to the thickness of the nut. The distance between the parallel sides of a bolt head and nut, and the thickness of the nut, shall be one-sixteenth of an inch less for finished work than for rough."

The foregoing is what is known as the Franklin Institute Standard, or as the Sellers' Standard, so named after its originator.

**United States Standard.**—The Navy Department appointed a Board to recommend a standard gauge for bolts, nuts, and screw threads for the United States Navy. On May 15, 1868, the Chief of Bureau of Steam Engineering submitted to the Secretary of the Navy the report of the Board indorsing the Sellers' system, but recommending certain modifications. Its recapitulation expresses the formula thus:

Let

$D$ = nominal diameter of bolt.
$p$ = pitch of thread.
$n$ = number of threads per inch.
$H$ = depth of nut.
$d_n$ = short diameter of hexagonal or square nut.
$d$ = effective diameter of bolt = diameter under root of thread.
$s$ = depth of thread.
$h$ = depth of head.
$d_h$ = short diameter of head.

Then

$$p = 0.24\sqrt{D + 0.625} - 0.175.$$
$$n = (\text{No. of threads per inch}) \frac{1}{p}.$$
$$s = 0.65\,p.$$
$$d = D - 2s = D - 1.3\,p.$$
$$H = D.$$
$$d_n = \tfrac{3}{2}D + \tfrac{1}{8}''$$
$$d_h = \tfrac{3}{2}D + \tfrac{1}{8}''$$
$$h = \tfrac{3}{4}D + \tfrac{1}{16}''$$

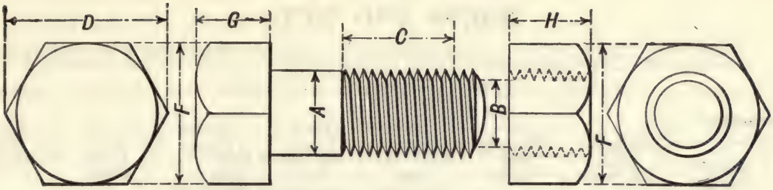
It then gives a table of screw threads the same as that recommended by the Franklin Institute, with the one difference and that regarding the size of finished or unfinished bolt heads and nuts. The Navy report makes no difference in the size of either—that is, for finished work the forgings must be made larger than for rough; their idea being to use the same wrench on either black or finished work. In reference to their tables: The only instance where the values in the table differ from those given by the formula is in the number of threads per inch, which is so far modified as to use the nearest convenient aliquot part of a unit, so as to avoid, as far as practicable, troublesome combinations in the gear of screw-cutting machines.

The Secretary of the Navy, in a communication to the Chief of Bureau of Steam Engineering, May 16, 1868, writes: "The standard for the dimensions of bolts and nuts, as determined by the Board, is, upon your recommendation, authorized for the naval service."

This constitutes what is known as the United States Standard; it corresponds in all respects to the Franklin Institute Standard for screw threads, but no difference in dimensions as between rough and finished bolt heads and nuts is made, one wrench serving for both.

This is the standard now in general use in the United States, but attention is drawn to the table of Standard Dimensions of Bolts and Nuts for the United States Navy, as given below. It will be observed that, beginning with 3 inches diameter of screw, the threads do not follow the authorized standard of 1868, inasmuch as all screw threads for bolts are uniformly 4 threads per inch from 3 inches up to and including 12 inches diameter.

# BOLTS AND NUTS




Standard Dimensions for United States Navy

| Diameters: Outside, Ins. | Diameters: Root of Thread, Inches | Effective Area Sq. Inches | Threads per Inch | Long Diam. Hex. Nut and Bolt-head | Long Diam. Sq. Nut and Bolt-head | Short Diam. Hex. & Sq. Nut and Bolt-head | Bolt-head, Depth | Nut, Depth |
|---|---|---|---|---|---|---|---|---|
| A | B | | C | D | E | F | G | H |
| $\frac{1}{4}$ | 0.185 | 0.026 | 20 | $\frac{9}{16}$ | $\frac{23}{32}$ | $\frac{1}{2}$ | $\frac{1}{4}$ | $\frac{1}{4}$ |
| $\frac{5}{16}$ | .240 | .045 | 18 | $\frac{11}{16}$ | $\frac{27}{32}$ | $\frac{19}{32}$ | $\frac{19}{64}$ | $\frac{5}{16}$ |
| $\frac{3}{8}$ | .294 | .067 | 16 | $\frac{25}{32}$ | $\frac{31}{32}$ | $\frac{11}{16}$ | $\frac{11}{32}$ | $\frac{3}{8}$ |
| $\frac{7}{16}$ | .345 | .093 | 14 | $\frac{29}{32}$ | $1\frac{3}{32}$ | $\frac{25}{32}$ | $\frac{25}{64}$ | $\frac{7}{16}$ |
| $\frac{1}{2}$ | .400 | .125 | 13 | 1 | $1\frac{1}{4}$ | $\frac{7}{8}$ | $\frac{7}{16}$ | $\frac{1}{2}$ |
| $\frac{9}{16}$ | .454 | .162 | 12 | $1\frac{1}{8}$ | $1\frac{3}{8}$ | $\frac{31}{32}$ | $\frac{31}{64}$ | $\frac{9}{16}$ |
| $\frac{5}{8}$ | .507 | .202 | 11 | $1\frac{7}{32}$ | $1\frac{1}{2}$ | $1\frac{1}{16}$ | $\frac{17}{32}$ | $\frac{5}{8}$ |
| $\frac{3}{4}$ | .620 | .302 | 10 | $1\frac{7}{16}$ | $1\frac{3}{4}$ | $1\frac{1}{4}$ | $\frac{5}{8}$ | $\frac{3}{4}$ |
| $\frac{7}{8}$ | .731 | .419 | 9 | $1\frac{21}{32}$ | $2\frac{1}{32}$ | $1\frac{7}{16}$ | $\frac{23}{32}$ | $\frac{7}{8}$ |
| 1 | .837 | .550 | 8 | $1\frac{7}{8}$ | $2\frac{5}{16}$ | $1\frac{5}{8}$ | $\frac{13}{16}$ | 1 |
| $1\frac{1}{8}$ | .940 | .694 | 7 | $2\frac{3}{32}$ | $2\frac{9}{16}$ | $1\frac{13}{16}$ | $\frac{29}{32}$ | $1\frac{1}{8}$ |
| $1\frac{1}{4}$ | 1.065 | .891 | 7 | $2\frac{5}{16}$ | $2\frac{27}{32}$ | 2 | 1 | $1\frac{1}{4}$ |
| $1\frac{3}{8}$ | 1.160 | 1.057 | 6 | $2\frac{17}{32}$ | $3\frac{3}{32}$ | $2\frac{3}{16}$ | $1\frac{3}{32}$ | $1\frac{3}{8}$ |
| $1\frac{1}{2}$ | 1.284 | 1.294 | 6 | $2\frac{3}{4}$ | $3\frac{11}{32}$ | $2\frac{3}{8}$ | $1\frac{3}{16}$ | $1\frac{1}{2}$ |
| $1\frac{5}{8}$ | 1.389 | 1.515 | $5\frac{1}{2}$ | $2\frac{31}{32}$ | $3\frac{5}{8}$ | $2\frac{9}{16}$ | $1\frac{9}{32}$ | $1\frac{5}{8}$ |
| $1\frac{3}{4}$ | 1.491 | 1.746 | 5 | $3\frac{3}{16}$ | $3\frac{7}{8}$ | $2\frac{3}{4}$ | $1\frac{3}{8}$ | $1\frac{3}{4}$ |
| $1\frac{7}{8}$ | 1.616 | 2.051 | 5 | $3\frac{13}{32}$ | $4\frac{5}{32}$ | $2\frac{15}{16}$ | $1\frac{15}{32}$ | $1\frac{7}{8}$ |
| 2 | 1.712 | 2.302 | $4\frac{1}{2}$ | $3\frac{19}{32}$ | $4\frac{13}{32}$ | $3\frac{1}{8}$ | $1\frac{9}{16}$ | 2 |
| $2\frac{1}{4}$ | 1.962 | 3.023 | $4\frac{1}{2}$ | $4\frac{1}{32}$ | $4\frac{15}{16}$ | $3\frac{1}{2}$ | $1\frac{3}{4}$ | $2\frac{1}{4}$ |
| $2\frac{1}{2}$ | 2.176 | 3.719 | 4 | $4\frac{15}{32}$ | $5\frac{15}{32}$ | $3\frac{7}{8}$ | $1\frac{15}{16}$ | $2\frac{1}{2}$ |
| $2\frac{3}{4}$ | 2.426 | 4.622 | 4 | $4\frac{29}{32}$ | 6 | $4\frac{1}{4}$ | $2\frac{1}{8}$ | $2\frac{3}{4}$ |
| 3 | 2.676 | 5.624 | 4 | $5\frac{11}{32}$ | $6\frac{17}{32}$ | $4\frac{5}{8}$ | $2\frac{5}{16}$ | 3 |
| $3\frac{1}{4}$ | 2.926 | 6.724 | 4 | $5\frac{25}{32}$ | $7\frac{1}{16}$ | 5 | $2\frac{1}{2}$ | $3\frac{1}{4}$ |
| $3\frac{1}{2}$ | 3.176 | 7.922 | 4 | $6\frac{7}{32}$ | $7\frac{19}{32}$ | $5\frac{3}{8}$ | $2\frac{11}{16}$ | $3\frac{1}{2}$ |
| $3\frac{3}{4}$ | 3.426 | 9.219 | 4 | $6\frac{5}{8}$ | $8\frac{1}{8}$ | $5\frac{3}{4}$ | $2\frac{7}{8}$ | $3\frac{3}{4}$ |
| 4 | 3.676 | 10.613 | 4 | $7\frac{1}{16}$ | $8\frac{21}{32}$ | $6\frac{1}{8}$ | $3\frac{1}{16}$ | 4 |
| $4\frac{1}{4}$ | 3.926 | 12.106 | 4 | $7\frac{1}{2}$ | $9\frac{3}{16}$ | $6\frac{1}{2}$ | $3\frac{1}{4}$ | $4\frac{1}{4}$ |
| $4\frac{1}{2}$ | 4.176 | 13.696 | 4 | $7\frac{15}{16}$ | $9\frac{29}{32}$ | $6\frac{7}{8}$ | $3\frac{7}{16}$ | $4\frac{1}{2}$ |
| $4\frac{3}{4}$ | 4.420 | 15.635 | 4 | $8\frac{3}{8}$ | $10\frac{1}{4}$ | $7\frac{1}{4}$ | $3\frac{5}{8}$ | $4\frac{3}{4}$ |
| 5 | 4.676 | 17.173 | 4 | $8\frac{13}{16}$ | $10\frac{25}{32}$ | $7\frac{5}{8}$ | $3\frac{13}{16}$ | 5 |
| $5\frac{1}{4}$ | 4.926 | 19.058 | 4 | $9\frac{1}{4}$ | $11\frac{5}{16}$ | 8 | 4 | $5\frac{1}{4}$ |
| $5\frac{1}{2}$ | 5.176 | 21.042 | 4 | $9\frac{11}{16}$ | $11\frac{27}{32}$ | $8\frac{3}{8}$ | $4\frac{3}{16}$ | $5\frac{1}{2}$ |
| $5\frac{3}{4}$ | 5.426 | 23.123 | 4 | $10\frac{3}{32}$ | $12\frac{3}{8}$ | $8\frac{3}{4}$ | $4\frac{3}{8}$ | $5\frac{3}{4}$ |
| 6 | -5.676 | 25.303 | 4 | $10\frac{17}{32}$ | $12\frac{29}{32}$ | $9\frac{1}{8}$ | $4\frac{9}{16}$ | 6 |

# BOLTS AND NUTS

Standard Dimensions for United States Navy. Sizes Over 6 Inches

| Diameters | | Effective Area, Sq. Inches | Threads per Inch | Long Diam. Hex. Nut and Bolt-head | Long Diam. Sq. Nut and Bolt-head | Short Diam. Hex. & Sq. Nut and Bolt-head | Bolt-head Depth | Nut Depth |
|---|---|---|---|---|---|---|---|---|
| Out-side, Ins. | Root of Thread, Inches | | | | | | | |
| A | B | | C | D | E | F | G | H |
| $6\frac{1}{4}$ | 5.926 | 27.58 | 4 | $10\frac{31}{32}$ | $13\frac{15}{32}$ | $9\frac{1}{2}$ | $4\frac{3}{4}$ | $6\frac{1}{4}$ |
| $6\frac{1}{2}$ | 6.176 | 29.95 | 4 | $11\frac{13}{32}$ | 14 | $9\frac{7}{8}$ | $4\frac{15}{16}$ | $6\frac{1}{2}$ |
| $6\frac{3}{4}$ | 6.426 | 32.43 | 4 | $11\frac{27}{32}$ | $14\frac{9}{16}$ | $10\frac{1}{4}$ | $5\frac{1}{8}$ | $6\frac{3}{4}$ |
| 7 | 6.676 | 35.00 | 4 | $12\frac{1}{4}$ | $15\frac{1}{8}$ | $10\frac{5}{8}$ | $5\frac{5}{16}$ | 7 |
| $7\frac{1}{4}$ | 6.926 | 37.68 | 4 | $12\frac{11}{16}$ | $15\frac{11}{16}$ | 11 | $5\frac{1}{2}$ | $7\frac{1}{4}$ |
| $7\frac{1}{2}$ | 7.176 | 40.44 | 4 | $13\frac{1}{8}$ | $16\frac{1}{4}$ | $11\frac{3}{8}$ | $5\frac{11}{16}$ | $7\frac{1}{2}$ |
| $7\frac{3}{4}$ | 7.426 | 43.30 | 4 | $13\frac{9}{16}$ | $16\frac{13}{16}$ | $11\frac{3}{4}$ | $5\frac{7}{8}$ | $7\frac{3}{4}$ |
| 8 | 7.676 | 46.27 | 4 | 14 | $17\frac{3}{8}$ | $12\frac{1}{8}$ | $6\frac{1}{16}$ | 8 |
| $8\frac{1}{4}$ | 7.926 | 49.35 | 4 | $14\frac{7}{16}$ | $17\frac{15}{16}$ | $12\frac{1}{2}$ | $6\frac{1}{4}$ | $8\frac{1}{4}$ |
| $8\frac{1}{2}$ | 8.176 | 52.52 | 4 | $14\frac{27}{32}$ | $18\frac{31}{32}$ | $12\frac{7}{8}$ | $6\frac{7}{16}$ | $8\frac{1}{2}$ |
| $8\frac{3}{4}$ | 8.426 | 55.76 | 4 | $15\frac{9}{32}$ | $19\frac{1}{32}$ | $13\frac{1}{4}$ | $6\frac{5}{8}$ | $8\frac{3}{4}$ |
| 9 | 8.676 | 59.90 | 4 | $15\frac{23}{32}$ | $19\frac{19}{32}$ | $13\frac{5}{8}$ | $6\frac{13}{16}$ | 9 |
| $9\frac{1}{4}$ | 8.926 | 62.57 | 4 | $16\frac{3}{16}$ | $19\frac{13}{16}$ | 14 | 7 | $9\frac{1}{4}$ |
| $9\frac{1}{2}$ | 9.176 | 66.13 | 4 | $16\frac{19}{32}$ | $20\frac{5}{16}$ | $14\frac{3}{8}$ | $7\frac{3}{16}$ | $9\frac{1}{2}$ |
| $9\frac{3}{4}$ | 9.426 | 69.77 | 4 | $17\frac{1}{16}$ | $20\frac{27}{32}$ | $14\frac{3}{4}$ | $7\frac{3}{8}$ | $9\frac{3}{4}$ |
| 10 | 9.676 | 73.52 | 4 | $17\frac{15}{32}$ | $21\frac{3}{8}$ | $15\frac{1}{8}$ | $7\frac{9}{16}$ | 10 |
| $10\frac{1}{4}$ | 9.926 | 77.38 | 4 | $17\frac{3}{4}$ | $21\frac{3}{4}$ | $15\frac{3}{8}$ | $7\frac{11}{16}$ | $10\frac{1}{4}$ |
| $10\frac{1}{2}$ | 10.176 | 81.33 | 4 | $18\frac{11}{16}$ | $22\frac{7}{16}$ | $15\frac{7}{8}$ | $7\frac{15}{16}$ | $10\frac{1}{2}$ |
| $10\frac{3}{4}$ | 10.426 | 85.34 | 4 | $18\frac{25}{32}$ | $22\frac{31}{32}$ | $16\frac{1}{4}$ | $8\frac{1}{8}$ | $10\frac{3}{4}$ |
| 11 | 10.676 | 89.52 | 4 | $19\frac{3}{16}$ | $23\frac{1}{2}$ | $16\frac{5}{8}$ | $8\frac{5}{16}$ | 11 |
| $11\frac{1}{4}$ | 10.926 | 93.76 | 4 | $19\frac{5}{8}$ | $24\frac{1}{32}$ | 17 | $8\frac{1}{2}$ | $11\frac{1}{4}$ |
| $11\frac{1}{2}$ | 11.176 | 98.10 | 4 | $20\frac{1}{16}$ | $24\frac{9}{16}$ | $17\frac{3}{8}$ | $8\frac{11}{16}$ | $11\frac{1}{2}$ |
| $11\frac{3}{4}$ | 11.426 | 102.53 | 4 | $20\frac{1}{2}$ | $25\frac{3}{32}$ | $17\frac{3}{4}$ | $8\frac{7}{8}$ | $11\frac{3}{4}$ |
| 12 | 11.676 | 107.07 | 4 | $21\frac{3}{32}$ | $25\frac{13}{16}$ | $18\frac{1}{4}$ | $9\frac{1}{8}$ | 12 |

## MAXIMUM WORKING LOAD FOR TABULAR TENSILE STRENGTH

### UNITED STATES NAVY

Forgings. High grade. Minimum tensile strength....................95,000
Forgings. High grade Class A. Minimum tensile strength..................80,000
Forgings. High grade Class B. Minimum tensile strength..................60,000

Bolts and boiler braces. Class A. Minimum tensile strength................75,000
Bolts and boiler braces. Class B. Minimum tensile strength................58,000

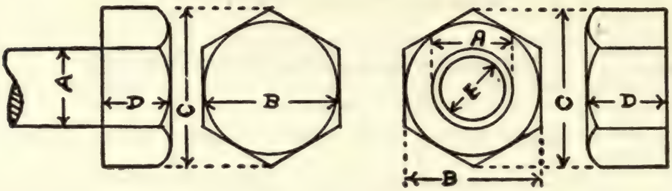
Rolled manganese and Tobin bronze and naval brass. Minimum tensile strength. 50,000
Phosphor bronze and Muntz metal. Minimum tensile strength..............40,000

## MAXIMUM WORKING LOAD FOR TABULAR TENSILE STRENGTH

UNITED STATES NAVY

| Bolt Details | | | Maximum Working Load for Tensile Strength F = | | | | | | | Factor of Safety |
|---|---|---|---|---|---|---|---|---|---|---|
| Outside Diam., Ins. | Diam. at Root of Thread | Effective Area, Sq. Ins. | 40,000 | 50,000 | 58,000 | 60,000 | 75,000 | 80,000 | 95,000 | |
| $\frac{1}{4}$ | 0.185 | 0.026 | 111 | 138 | 160 | 166 | 206 | 221 | 261 | 9.4 |
| $\frac{5}{16}$ | .240 | .045 | 198 | 247 | 287 | 297 | 370 | 396 | 470 | 9.1 |
| $\frac{3}{8}$ | .294 | .067 | 301 | 376 | 435 | 451 | 560 | 601 | 714 | 9.0 |
| $\frac{7}{16}$ | .345 | .093 | 415 | 519 | 600 | 623 | 775 | 830 | 986 | 8.9 |
| $\frac{1}{2}$ | .400 | .125 | 564 | 704 | 818 | 845 | 1,055 | 1,125 | 1,340 | 8.9 |
| $\frac{9}{16}$ | .454 | .162 | 730 | 912 | 1,060 | 1,095 | 1,370 | 1,460 | 1,730 | 8.9 |
| $\frac{5}{8}$ | .507 | .202 | 913 | 1,140 | 1,300 | 1,370 | 1,700 | 1,870 | 2,170 | 8.8 |
| $\frac{3}{4}$ | .620 | .302 | 1,380 | 1,725 | 2,000 | 2,070 | 2,580 | 2,760 | 3,280 | 8.8 |
| $\frac{7}{8}$ | .731 | .419 | 1,930 | 2,410 | 2,800 | 2,900 | 3,600 | 3,860 | 4,580 | 8.7 |
| 1 | .837 | .550 | 2,530 | 3,170 | 3,670 | 3,800 | 4,700 | 5,060 | 6,010 | 8.7 |
| $1\frac{1}{8}$ | .940 | .694 | 3,190 | 3,990 | 4,600 | 4,790 | 5,980 | 6,380 | 7,570 | 8.7 |
| $1\frac{1}{4}$ | 1.065 | .891 | 4,140 | 5,180 | 6,000 | 6,210 | 7,760 | 8,280 | 9,830 | 8.6 |
| $1\frac{3}{8}$ | 1.160 | 1.057 | 4,890 | 6,110 | 7,080 | 7,330 | 9,150 | 9,780 | 11,600 | 8.7 |
| $1\frac{1}{2}$ | 1.284 | 1.294 | 6,040 | 7,540 | 8,760 | 9,060 | 11,300 | 12,050 | 14,300 | 8.6 |
| $1\frac{5}{8}$ | 1.389 | 1.515 | 7,060 | 8,820 | 10,200 | 10,600 | 13,200 | 14,100 | 16,750 | 8.6 |
| $1\frac{3}{4}$ | 1.491 | 1.746 | 8,120 | 10,150 | 11,770 | 12,200 | 15,200 | 16,200 | 19,250 | 8.6 |
| $1\frac{7}{8}$ | 1.616 | 2.051 | 9,600 | 12,000 | 13,900 | 14,400 | 18,000 | 19,200 | 22,800 | 8.5 |
| 2 | 1.712 | 2.302 | 10,750 | 13,400 | 15,500 | 16,100 | 20,100 | 21,500 | 25,500 | 8.6 |
| $2\frac{1}{4}$ | 1.962 | 3.023 | 14,200 | 17,800 | 20,600 | 21,400 | 26,700 | 28,500 | 33,800 | 8.5 |
| $2\frac{1}{2}$ | 2.176 | 3.719 | 17,500 | 21,900 | 25,300 | 26,300 | 32,800 | 35,000 | 41,500 | 8.5 |
| $2\frac{3}{4}$ | 2.426 | 4.622 | 22,000 | 27,500 | 31,900 | 33,000 | 41,200 | 44,000 | 52,200 | 8.4 |
| 3 | 2.676 | 5.624 | 26,800 | 33,500 | 38,800 | 40,200 | 50,200 | 53,600 | 63,600 | 8.4 |
| $3\frac{1}{4}$ | 2.926 | 6.724 | 32,200 | 40,200 | 46,700 | 48,400 | 60,400 | 64,400 | 76,400 | 8.3 |
| $3\frac{1}{2}$ | 3.176 | 7.922 | 38,100 | 47,600 | 55,100 | 57,200 | 71,200 | 76,200 | 90,400 | 8.3 |
| $3\frac{3}{4}$ | 3.426 | 9.219 | 44,500 | 55,600 | 64,300 | 66,700 | 83,200 | 89,000 | 105,500 | 8.3 |
| 4 | 3.676 | 10.613 | 51,400 | 64,200 | 74,500 | 77,000 | 96,400 | 102,800 | 122,000 | 8.3 |
| $4\frac{1}{4}$ | 3.926 | 12.106 | 58,700 | 73,400 | 85,100 | 88,100 | 110,000 | 117,400 | 139,300 | 8.2 |
| $4\frac{1}{2}$ | 4.176 | 13.696 | 66,600 | 83,200 | 96,500 | 100,000 | 124,900 | 133,000 | 158,000 | 8.2 |
| $4\frac{3}{4}$ | 4.420 | 15.635 | 75,000 | 93,700 | 108,400 | 112,000 | 140,200 | 150,000 | 178,000 | 8.2 |
| 5 | 4.676 | 17.173 | 83,800 | 105,000 | 121,500 | 126,000 | 157,100 | 167,500 | 199,000 | 8.2 |
| $5\frac{1}{4}$ | 4.926 | 19.058 | 93,200 | 116,500 | 135,000 | 140,000 | 174,800 | 186,000 | 221,000 | 8.2 |
| $5\frac{1}{2}$ | 5.176 | 21.042 | 103,000 | 129,000 | 149,000 | 154,500 | 193,100 | 206,000 | 244,500 | 8.2 |
| $5\frac{3}{4}$ | 5.426 | 23.123 | 113,500 | 142,000 | 164,000 | 170,000 | 212,600 | 227,000 | 269,000 | 8.2 |
| 6 | 5.676 | 25.303 | 124,000 | 155,000 | 179,800 | 186,000 | 232,500 | 248,000 | 295,000 | 8.1 |

# WEIGHT OF HEXAGON BOLT-HEADS AND NUTS

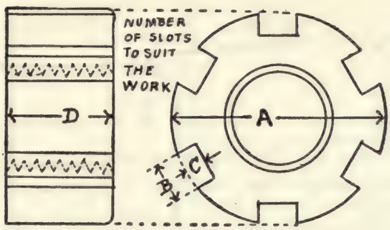



United States Standard Dimensions

| Bar | | | | Head | | | | | Nut | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Diam. A | Area | Weight Inch | Weight Foot | Sh't Dia. B | Area Hexagon Square In. | Hght. D | Content Cubic Inch | Weight of Head | Sh't Dia. B | Hght. D | Hole Dia. E | Weight |
| $\frac{1}{4}$ | .049 | .014 | .167 | $\frac{1}{2}$ | .217 | $\frac{1}{4}$ | .054 | .015 | $\frac{1}{2}$ | $\frac{1}{4}$ | $\frac{3}{16}$ | .014 |
| $\frac{5}{16}$ | .077 | .022 | .261 | $\frac{19}{32}$ | .305 | $\frac{19}{64}$ | .091 | .026 | $\frac{19}{32}$ | $\frac{5}{16}$ | $\frac{1}{4}$ | .022 |
| $\frac{3}{8}$ | .110 | .031 | .375 | $\frac{11}{16}$ | .409 | $\frac{11}{32}$ | .141 | .040 | $\frac{11}{16}$ | $\frac{3}{8}$ | $\frac{19}{64}$ | .036 |
| $\frac{7}{16}$ | .150 | .043 | .511 | $\frac{25}{32}$ | .529 | $\frac{25}{64}$ | .207 | .059 | $\frac{25}{32}$ | $\frac{7}{16}$ | $\frac{11}{32}$ | .053 |
| $\frac{1}{2}$ | .196 | .056 | .667 | $\frac{7}{8}$ | .663 | $\frac{7}{16}$ | .290 | .082 | $\frac{7}{8}$ | $\frac{1}{2}$ | $\frac{25}{64}$ | .075 |
| $\frac{9}{16}$ | .249 | .070 | .845 | $\frac{31}{32}$ | .813 | $\frac{31}{64}$ | .394 | .112 | $\frac{31}{32}$ | $\frac{9}{16}$ | $\frac{29}{64}$ | .100 |
| $\frac{5}{8}$ | .307 | .087 | 1.043 | $1\frac{1}{16}$ | .979 | $\frac{17}{32}$ | .520 | .147 | $1\frac{1}{16}$ | $\frac{5}{8}$ | $\frac{33}{64}$ | .139 |
| $\frac{3}{4}$ | .442 | .125 | 1.502 | $1\frac{1}{4}$ | 1.353 | $\frac{5}{8}$ | .846 | .240 | $1\frac{1}{4}$ | $\frac{3}{4}$ | $\frac{39}{64}$ | .223 |
| $\frac{7}{8}$ | .601 | .170 | 2.044 | $1\frac{7}{16}$ | 1.791 | $\frac{23}{32}$ | 1.287 | .365 | $1\frac{7}{16}$ | $\frac{7}{8}$ | $\frac{47}{64}$ | .353 |
| 1 | .785 | .222 | 2.670 | $1\frac{5}{8}$ | 2.287 | $\frac{13}{16}$ | 1.858 | .526 | $1\frac{5}{8}$ | 1 | $\frac{53}{64}$ | .490 |
| $1\frac{1}{8}$ | .994 | .282 | 3.379 | $1\frac{13}{16}$ | 2.847 | $\frac{29}{32}$ | 2.580 | .731 | $1\frac{13}{16}$ | $1\frac{1}{8}$ | $\frac{59}{64}$ | .676 |
| $1\frac{1}{4}$ | 1.227 | .348 | 4.173 | 2 | 3.464 | 1 | 3.464 | .981 | 2 | $1\frac{1}{4}$ | $1\frac{1}{16}$ | .962 |
| $1\frac{3}{8}$ | 1.485 | .421 | 5.049 | $2\frac{3}{16}$ | 4.156 | $1\frac{3}{32}$ | 4.546 | 1.288 | $2\frac{3}{16}$ | $1\frac{3}{8}$ | $1\frac{5}{32}$ | 1.220 |
| $1\frac{1}{2}$ | 1.767 | .501 | 6.008 | $2\frac{3}{8}$ | 4.885 | $1\frac{3}{16}$ | 5.801 | 1.644 | $2\frac{3}{8}$ | $1\frac{1}{2}$ | $1\frac{9}{32}$ | 1.515 |
| $1\frac{5}{8}$ | 2.074 | .588 | 7.051 | $2\frac{9}{16}$ | 5.689 | $1\frac{9}{32}$ | 7.289 | 2.065 | $2\frac{9}{16}$ | $1\frac{5}{8}$ | $1\frac{25}{64}$ | 1.852 |
| $1\frac{3}{4}$ | 2.405 | .681 | 8.18 | $2\frac{3}{4}$ | 6.549 | $1\frac{3}{8}$ | 9.005 | 2.551 | $2\frac{3}{4}$ | $1\frac{3}{4}$ | $1\frac{1}{2}$ | 2.272 |
| $1\frac{7}{8}$ | 2.761 | .782 | 9.39 | $2\frac{15}{16}$ | 7.475 | $1\frac{15}{32}$ | 10.979 | 3.111 | $2\frac{15}{16}$ | $1\frac{7}{8}$ | $1\frac{5}{8}$ | 2.817 |
| 2 | 3.142 | .890 | 10.68 | $3\frac{1}{8}$ | 8.457 | $1\frac{9}{16}$ | 13.214 | 3.744 | $3\frac{1}{8}$ | 2 | $1\frac{23}{32}$ | 3.333 |
| $2\frac{1}{4}$ | 3.976 | 1.127 | 13.52 | $3\frac{1}{2}$ | 10.609 | $1\frac{3}{4}$ | 18.566 | 5.260 | $3\frac{1}{2}$ | $2\frac{1}{4}$ | $1\frac{31}{32}$ | 4.823 |
| $2\frac{1}{2}$ | 4.909 | 1.391 | 16.69 | $3\frac{7}{8}$ | 13.004 | $1\frac{15}{16}$ | 25.195 | 7.138 | $3\frac{7}{8}$ | $2\frac{1}{2}$ | $2\frac{3}{16}$ | 6.549 |
| $2\frac{3}{4}$ | 5.940 | 1.683 | 20.20 | $4\frac{1}{4}$ | 15.642 | $2\frac{1}{8}$ | 33.239 | 9.418 | $4\frac{1}{4}$ | $2\frac{3}{4}$ | $2\frac{7}{16}$ | 8.552 |
| 3 | 7.069 | 2.002 | 24.03 | $4\frac{5}{8}$ | 18.524 | $2\frac{5}{16}$ | 42.837 | 12.137 | $4\frac{5}{8}$ | 3 | $2\frac{11}{16}$ | 10.924 |
| $3\frac{1}{4}$ | 8.296 | 2.350 | 28.20 | 5 | 21.650 | $2\frac{1}{2}$ | 54.125 | 15.335 | 5 | $3\frac{1}{4}$ | $2\frac{15}{16}$ | 13.695 |
| $3\frac{1}{2}$ | 9.621 | 2.726 | 32.71 | $5\frac{3}{8}$ | 25.019 | $2\frac{11}{16}$ | 67.239 | 19.051 | $5\frac{3}{8}$ | $3\frac{1}{2}$ | $3\frac{3}{16}$ | 16.897 |
| $3\frac{3}{4}$ | 11.045 | 3.130 | 37.56 | $5\frac{3}{4}$ | 28.632 | $2\frac{7}{8}$ | 82.317 | 23.323 | $5\frac{3}{4}$ | $3\frac{3}{4}$ | $3\frac{7}{16}$ | 20.560 |
| 4 | 12.566 | 3.561 | 42.73 | $6\frac{1}{8}$ | 32.488 | $3\frac{1}{16}$ | 99.495 | 28.190 | $6\frac{1}{8}$ | 4 | $3\frac{11}{16}$ | 24.715 |

# ROUND SLOTTED NUTS

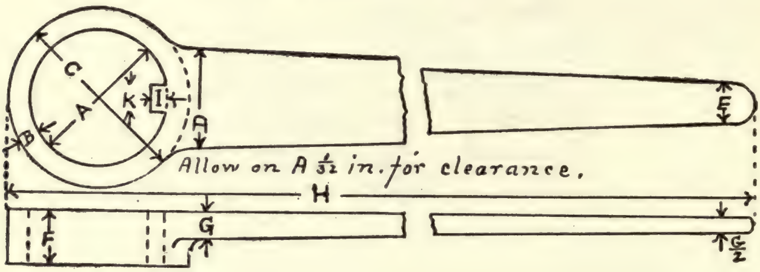
## NAVY DEPARTMENT




| Diam. Bolt | A | B | C | D | Diam. Bolt | A | B | C | D |
|---|---|---|---|---|---|---|---|---|---|
| $\frac{3}{4}$ | $1\frac{5}{8}$ | $\frac{5}{16}$ | $\frac{1}{8}$ | $\frac{3}{4}$ | $5\frac{3}{4}$ | $9\frac{3}{4}$ | $1\frac{1}{4}$ | $\frac{1}{2}$ | $5\frac{3}{4}$ |
| $\frac{7}{8}$ | $1\frac{7}{8}$ | $\frac{5}{16}$ | $\frac{1}{8}$ | $\frac{7}{8}$ | 6 | $10\frac{1}{4}$ | $1\frac{1}{4}$ | $\frac{1}{2}$ | 6 |
| 1 | 2 | $\frac{3}{8}$ | $\frac{3}{16}$ | 1 | $6\frac{1}{4}$ | $10\frac{5}{8}$ | $1\frac{1}{4}$ | $\frac{1}{2}$ | $6\frac{1}{4}$ |
| $1\frac{1}{8}$ | $2\frac{1}{4}$ | $\frac{3}{8}$ | $\frac{3}{16}$ | $1\frac{1}{8}$ | $6\frac{1}{2}$ | 11 | $1\frac{3}{8}$ | $\frac{9}{16}$ | $6\frac{1}{2}$ |
| $1\frac{1}{4}$ | $2\frac{1}{2}$ | $\frac{3}{8}$ | $\frac{3}{16}$ | $1\frac{1}{4}$ | $6\frac{3}{4}$ | $11\frac{1}{2}$ | $1\frac{3}{8}$ | $\frac{9}{16}$ | $6\frac{3}{4}$ |
| $1\frac{3}{8}$ | $2\frac{5}{8}$ | $\frac{7}{16}$ | $\frac{3}{16}$ | $1\frac{3}{8}$ | 7 | $11\frac{7}{8}$ | $1\frac{3}{8}$ | $\frac{9}{16}$ | 7 |
| $1\frac{1}{2}$ | $2\frac{7}{8}$ | $\frac{7}{16}$ | $\frac{3}{16}$ | $1\frac{1}{2}$ | $7\frac{1}{4}$ | $12\frac{1}{4}$ | $1\frac{1}{2}$ | $\frac{9}{16}$ | $7\frac{1}{4}$ |
| $1\frac{5}{8}$ | $3\frac{1}{8}$ | $\frac{7}{16}$ | $\frac{3}{16}$ | $1\frac{5}{8}$ | $7\frac{1}{2}$ | $12\frac{5}{8}$ | $1\frac{1}{2}$ | $\frac{5}{8}$ | $7\frac{1}{2}$ |
| $1\frac{3}{4}$ | $3\frac{1}{4}$ | $\frac{1}{2}$ | $\frac{3}{16}$ | $1\frac{3}{4}$ | $7\frac{3}{4}$ | 13 | $1\frac{1}{2}$ | $\frac{5}{8}$ | $7\frac{3}{4}$ |
| $1\frac{7}{8}$ | $3\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{1}{4}$ | $1\frac{7}{8}$ | 8 | $13\frac{1}{2}$ | $1\frac{1}{2}$ | $\frac{5}{8}$ | 8 |
| 2 | $3\frac{5}{8}$ | $\frac{1}{2}$ | $\frac{1}{4}$ | 2 | $8\frac{1}{4}$ | $13\frac{7}{8}$ | $1\frac{5}{8}$ | $\frac{5}{8}$ | $8\frac{1}{4}$ |
| $2\frac{1}{4}$ | $4\frac{1}{8}$ | $\frac{9}{16}$ | $\frac{1}{4}$ | $2\frac{1}{4}$ | $8\frac{1}{2}$ | $14\frac{1}{4}$ | $1\frac{5}{8}$ | $\frac{11}{16}$ | $8\frac{1}{2}$ |
| $2\frac{1}{2}$ | $4\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{1}{4}$ | $2\frac{1}{2}$ | $8\frac{3}{4}$ | $14\frac{3}{4}$ | $1\frac{5}{8}$ | $\frac{11}{16}$ | $8\frac{3}{4}$ |
| $2\frac{3}{4}$ | $4\frac{7}{8}$ | $\frac{5}{8}$ | $\frac{5}{16}$ | $2\frac{3}{4}$ | 9 | $15\frac{1}{8}$ | $1\frac{3}{4}$ | $\frac{11}{16}$ | 9 |
| 3 | $5\frac{1}{4}$ | $\frac{11}{16}$ | $\frac{5}{16}$ | 3 | $9\frac{1}{4}$ | $15\frac{1}{2}$ | $1\frac{3}{4}$ | $\frac{11}{16}$ | $9\frac{1}{4}$ |
| $3\frac{1}{4}$ | $5\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{5}{16}$ | $3\frac{1}{4}$ | $9\frac{1}{2}$ | 16 | $1\frac{3}{4}$ | $\frac{3}{4}$ | $9\frac{1}{2}$ |
| $3\frac{1}{2}$ | $6\frac{1}{8}$ | $\frac{3}{4}$ | $\frac{5}{16}$ | $3\frac{1}{2}$ | $9\frac{3}{4}$ | $16\frac{3}{8}$ | $1\frac{7}{8}$ | $\frac{3}{4}$ | $9\frac{3}{4}$ |
| $3\frac{3}{4}$ | $6\frac{1}{2}$ | $\frac{13}{16}$ | $\frac{3}{8}$ | $3\frac{3}{4}$ | 10 | $16\frac{3}{4}$ | $1\frac{7}{8}$ | $\frac{3}{4}$ | 10 |
| 4 | $6\frac{7}{8}$ | $\frac{7}{8}$ | $\frac{3}{8}$ | 4 | $10\frac{1}{4}$ | $17\frac{1}{8}$ | $1\frac{7}{8}$ | $\frac{13}{16}$ | $10\frac{1}{4}$ |
| $4\frac{1}{4}$ | $7\frac{3}{8}$ | $\frac{15}{16}$ | $\frac{3}{8}$ | $4\frac{1}{4}$ | $10\frac{1}{2}$ | $17\frac{1}{2}$ | $1\frac{7}{8}$ | $\frac{13}{16}$ | $10\frac{1}{2}$ |
| $4\frac{1}{2}$ | $7\frac{3}{4}$ | 1 | $\frac{3}{8}$ | $4\frac{1}{2}$ | $10\frac{3}{4}$ | 18 | 2 | $\frac{13}{16}$ | $10\frac{3}{4}$ |
| $4\frac{3}{4}$ | $8\frac{1}{8}$ | 1 | $\frac{7}{16}$ | $4\frac{3}{4}$ | 11 | $18\frac{3}{8}$ | 2 | $\frac{7}{8}$ | 11 |
| 5 | $8\frac{1}{2}$ | $1\frac{1}{8}$ | $\frac{7}{16}$ | 5 | $11\frac{1}{2}$ | $19\frac{1}{4}$ | $2\frac{1}{8}$ | $\frac{7}{8}$ | $11\frac{1}{2}$ |
| $5\frac{1}{4}$ | 9 | $1\frac{1}{8}$ | $\frac{7}{16}$ | $5\frac{1}{4}$ | 12 | 20 | $2\frac{1}{4}$ | $\frac{7}{8}$ | 12 |
| $5\frac{1}{2}$ | $9\frac{3}{8}$ | $1\frac{1}{8}$ | $\frac{7}{16}$ | $5\frac{1}{2}$ | | | | | |

# BOX WRENCHES FOR HEXAGON AND ROUND SLOTTED NUTS

## NAVY DEPARTMENT

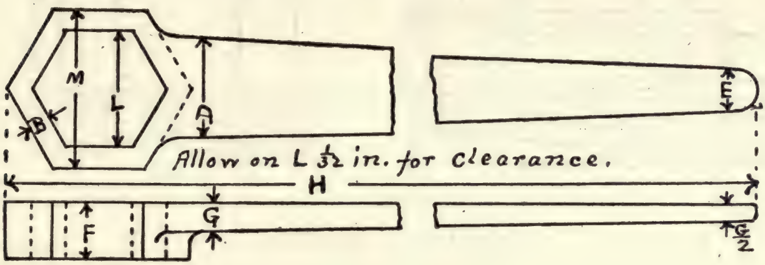



| Diam. Bolt | A | B | C | D | E | F | G | H | I | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\frac{3}{4}$ | $1\frac{5}{8}$ | $\frac{1}{4}$ | $2\frac{1}{8}$ | $1\frac{1}{4}$ | $\frac{7}{8}$ | $\frac{3}{8}$ | $\frac{3}{8}$ | 12″ | $\frac{3}{16}$ | $\frac{5}{16}$ | $1\frac{1}{4}$ | $1\frac{5}{8}$ |
| $\frac{7}{8}$ | $1\frac{7}{8}$ | $\frac{1}{4}$ | $2\frac{5}{16}$ | $1\frac{3}{8}$ | $\frac{7}{8}$ | $\frac{5}{8}$ | $\frac{3}{8}$ | $13\frac{1}{2}$″ | $\frac{3}{16}$ | $\frac{5}{16}$ | $1\frac{7}{16}$ | $1\frac{13}{16}$ |
| 1 | 2 | $\frac{5}{16}$ | $2\frac{5}{8}$ | $1\frac{1}{2}$ | $\frac{7}{8}$ | $\frac{3}{4}$ | $\frac{7}{16}$ | 15″ | $\frac{3}{16}$ | $\frac{3}{8}$ | $1\frac{5}{8}$ | 2 |
| $1\frac{1}{8}$ | $2\frac{1}{4}$ | $\frac{5}{16}$ | $2\frac{7}{8}$ | $1\frac{5}{8}$ | $\frac{7}{8}$ | $\frac{3}{4}$ | $\frac{7}{16}$ | $16\frac{1}{2}$″ | $\frac{3}{16}$ | $\frac{3}{8}$ | $1\frac{13}{16}$ | $2\frac{1}{4}$ |
| $1\frac{1}{4}$ | $2\frac{1}{2}$ | $\frac{5}{16}$ | 3 | $1\frac{3}{4}$ | 1 | $\frac{7}{8}$ | $\frac{7}{16}$ | 18″ | $\frac{3}{16}$ | $\frac{3}{8}$ | 2 | $2\frac{3}{8}$ |
| $1\frac{3}{8}$ | $2\frac{5}{8}$ | $\frac{5}{16}$ | $3\frac{3}{4}$ | $1\frac{3}{4}$ | 1 | $\frac{7}{8}$ | $\frac{1}{2}$ | $19\frac{1}{2}$″ | $\frac{3}{16}$ | $\frac{7}{16}$ | $2\frac{3}{16}$ | $2\frac{5}{8}$ |
| $1\frac{1}{2}$ | $2\frac{7}{8}$ | $\frac{3}{8}$ | $3\frac{5}{8}$ | $1\frac{7}{8}$ | 1 | 1 | $\frac{1}{2}$ | 21″ | $\frac{7}{32}$ | $\frac{7}{16}$ | $2\frac{3}{8}$ | $2\frac{7}{8}$ |
| $1\frac{5}{8}$ | $3\frac{1}{8}$ | $\frac{3}{8}$ | $3\frac{3}{4}$ | $1\frac{7}{8}$ | 1 | 1 | $\frac{9}{16}$ | $22\frac{1}{2}$″ | $\frac{7}{32}$ | $\frac{7}{16}$ | $2\frac{9}{16}$ | 3 |
| $1\frac{3}{4}$ | $3\frac{1}{4}$ | $\frac{7}{16}$ | $4\frac{1}{8}$ | 2 | $1\frac{1}{8}$ | $1\frac{1}{8}$ | $\frac{9}{16}$ | 24″ | $\frac{1}{4}$ | $\frac{1}{2}$ | $2\frac{3}{4}$ | $3\frac{1}{4}$ |
| $1\frac{7}{8}$ | $3\frac{1}{2}$ | $\frac{7}{16}$ | $4\frac{3}{8}$ | 2 | $1\frac{1}{8}$ | $1\frac{1}{8}$ | $\frac{5}{8}$ | $2'1\frac{1}{2}$″ | $\frac{1}{4}$ | $\frac{1}{2}$ | $2\frac{15}{16}$ | $3\frac{1}{2}$ |
| 2 | $3\frac{5}{8}$ | $\frac{1}{2}$ | $4\frac{5}{8}$ | $2\frac{1}{8}$ | $1\frac{1}{8}$ | $1\frac{1}{4}$ | $\frac{5}{8}$ | 2′3″ | $\frac{1}{4}$ | $\frac{1}{2}$ | $3\frac{1}{8}$ | $3\frac{5}{8}$ |
| $2\frac{1}{4}$ | $4\frac{1}{8}$ | $\frac{1}{2}$ | 5 | $2\frac{1}{4}$ | $1\frac{1}{4}$ | $1\frac{3}{8}$ | $\frac{5}{8}$ | 2′6″ | $\frac{1}{4}$ | $\frac{9}{16}$ | $3\frac{1}{2}$ | 4 |
| $2\frac{1}{2}$ | $4\frac{1}{2}$ | $\frac{9}{16}$ | $5\frac{1}{2}$ | $2\frac{3}{8}$ | $1\frac{1}{4}$ | $1\frac{1}{2}$ | $\frac{11}{16}$ | 2′9″ | $\frac{1}{4}$ | $\frac{5}{8}$ | $3\frac{7}{8}$ | $4\frac{3}{8}$ |
| $2\frac{3}{4}$ | $4\frac{7}{8}$ | $\frac{5}{8}$ | 6 | $2\frac{1}{2}$ | $1\frac{3}{8}$ | $1\frac{5}{8}$ | $\frac{3}{4}$ | 3′0″ | $\frac{1}{4}$ | $\frac{5}{8}$ | $4\frac{1}{4}$ | $4\frac{3}{4}$ |
| 3 | $5\frac{1}{4}$ | $\frac{11}{16}$ | $6\frac{5}{8}$ | $2\frac{3}{4}$ | $1\frac{3}{8}$ | $1\frac{3}{4}$ | $\frac{13}{16}$ | 3′2″ | $\frac{5}{16}$ | $\frac{11}{16}$ | $4\frac{5}{8}$ | $5\frac{1}{4}$ |
| $3\frac{1}{4}$ | $5\frac{5}{8}$ | $\frac{11}{16}$ | 7 | $2\frac{7}{8}$ | $1\frac{1}{2}$ | $1\frac{7}{8}$ | $\frac{7}{8}$ | 3′5″ | $\frac{5}{16}$ | $\frac{3}{4}$ | 5 | $5\frac{5}{8}$ |
| $3\frac{1}{2}$ | $6\frac{1}{8}$ | $\frac{3}{4}$ | $7\frac{1}{2}$ | 3 | $1\frac{1}{2}$ | 2 | $\frac{7}{8}$ | 3′8″ | $\frac{5}{16}$ | $\frac{3}{4}$ | $5\frac{3}{8}$ | 6 |
| $3\frac{3}{4}$ | $6\frac{1}{2}$ | $\frac{3}{4}$ | $7\frac{3}{4}$ | $3\frac{1}{8}$ | $1\frac{1}{2}$ | $2\frac{1}{8}$ | $\frac{15}{16}$ | 3′10″ | $\frac{5}{16}$ | $\frac{13}{16}$ | $5\frac{3}{4}$ | $6\frac{1}{4}$ |
| 4 | $6\frac{7}{8}$ | $\frac{7}{8}$ | $8\frac{5}{8}$ | $3\frac{1}{4}$ | $1\frac{5}{8}$ | $2\frac{1}{4}$ | 1 | 4′1″ | $\frac{3}{8}$ | $\frac{7}{8}$ | $6\frac{1}{8}$ | $6\frac{7}{8}$ |
| $4\frac{1}{4}$ | $7\frac{3}{8}$ | $\frac{7}{8}$ | 9 | $3\frac{1}{2}$ | $1\frac{5}{8}$ | $2\frac{3}{8}$ | $1\frac{1}{16}$ | 4′4″ | $\frac{3}{8}$ | $\frac{15}{16}$ | $6\frac{1}{2}$ | $7\frac{1}{4}$ |
| $4\frac{1}{2}$ | $7\frac{3}{4}$ | 1 | $9\frac{5}{8}$ | $3\frac{5}{8}$ | $1\frac{3}{4}$ | $2\frac{1}{2}$ | $1\frac{1}{8}$ | 4′6″ | $\frac{3}{8}$ | 1 | $6\frac{7}{8}$ | $7\frac{5}{8}$ |
| $4\frac{3}{4}$ | $8\frac{1}{8}$ | 1 | 10 | $3\frac{3}{4}$ | $1\frac{3}{4}$ | $2\frac{5}{8}$ | $1\frac{1}{8}$ | 4′9″ | $\frac{3}{8}$ | 1 | $7\frac{1}{4}$ | 8 |
| 5 | $8\frac{1}{2}$ | $1\frac{1}{16}$ | $10\frac{5}{8}$ | $3\frac{7}{8}$ | $1\frac{7}{8}$ | $2\frac{3}{4}$ | $1\frac{3}{16}$ | 5′0″ | $\frac{7}{16}$ | $1\frac{1}{8}$ | $7\frac{5}{8}$ | $8\frac{1}{2}$ |
| $5\frac{1}{4}$ | 9 | $1\frac{1}{16}$ | 11 | 4 | $1\frac{7}{8}$ | $2\frac{3}{4}$ | $1\frac{1}{4}$ | 5′3″ | $\frac{7}{16}$ | $1\frac{1}{8}$ | 8 | $8\frac{7}{8}$ |
| $5\frac{1}{2}$ | $9\frac{3}{8}$ | $1\frac{1}{8}$ | $11\frac{1}{2}$ | $4\frac{1}{8}$ | 2 | $2\frac{7}{8}$ | $1\frac{1}{4}$ | 5′6″ | $\frac{7}{16}$ | $1\frac{1}{8}$ | $8\frac{3}{8}$ | $9\frac{1}{4}$ |

# BOX WRENCHES FOR HEXAGON AND ROUND SLOTTED NUTS

(*Continued*)

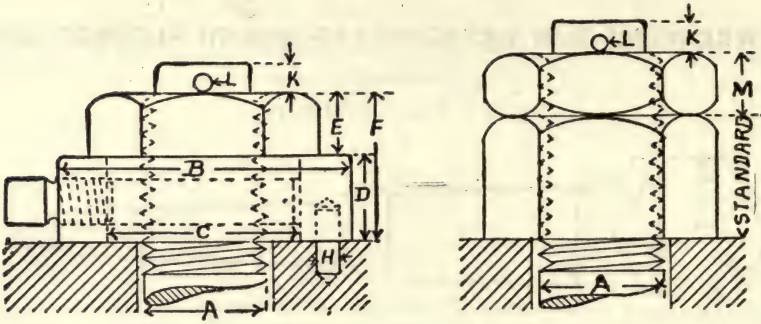
## NAVY DEPARTMENT




| Diam. Bolt | A | B | C | D | E | F | G | H | I | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $5\frac{3}{4}$ | $9\frac{3}{4}$ | $1\frac{1}{8}$ | $11\frac{7}{8}$ | $4\frac{1}{4}$ | 2 | 3 | $1\frac{5}{16}$ | 5′9″ | $\frac{7}{16}$ | $1\frac{1}{4}$ | $8\frac{3}{4}$ | $9\frac{5}{8}$ |
| 6 | $10\frac{1}{4}$ | $1\frac{1}{4}$ | $12\frac{5}{8}$ | $4\frac{1}{2}$ | $2\frac{1}{8}$ | $3\frac{1}{8}$ | $1\frac{3}{8}$ | 6′0″ | $\frac{1}{2}$ | $1\frac{1}{4}$ | $9\frac{1}{8}$ | $10\frac{1}{8}$ |
| $6\frac{1}{4}$ | $10\frac{5}{8}$ | $1\frac{1}{4}$ | 13 | $4\frac{5}{8}$ | $2\frac{1}{8}$ | $3\frac{1}{4}$ | $1\frac{7}{16}$ | .... | $\frac{1}{2}$ | $1\frac{1}{4}$ | $9\frac{1}{2}$ | $10\frac{1}{2}$ |
| $6\frac{1}{2}$ | 11 | $1\frac{3}{8}$ | $13\frac{5}{8}$ | $4\frac{3}{4}$ | $2\frac{1}{4}$ | $3\frac{3}{8}$ | $1\frac{7}{16}$ | .... | $\frac{1}{2}$ | $1\frac{3}{8}$ | $9\frac{7}{8}$ | $10\frac{7}{8}$ |
| $6\frac{3}{4}$ | $11\frac{1}{2}$ | $1\frac{3}{8}$ | 14 | 5 | $2\frac{1}{4}$ | $3\frac{1}{2}$ | $1\frac{1}{2}$ | .... | $\frac{1}{2}$ | $1\frac{3}{8}$ | $10\frac{1}{4}$ | $11\frac{1}{4}$ |
| 7 | $11\frac{7}{8}$ | $1\frac{7}{16}$ | $14\frac{5}{8}$ | $5\frac{1}{8}$ | $2\frac{1}{4}$ | $3\frac{5}{8}$ | $1\frac{9}{16}$ | .... | $\frac{9}{16}$ | $1\frac{3}{8}$ | $10\frac{5}{8}$ | $11\frac{3}{4}$ |
| $7\frac{1}{4}$ | $12\frac{1}{4}$ | $1\frac{1}{2}$ | $15\frac{1}{8}$ | $5\frac{1}{4}$ | $2\frac{3}{8}$ | $3\frac{3}{4}$ | $1\frac{5}{8}$ | .... | $\frac{9}{16}$ | $1\frac{1}{2}$ | 11 | $12\frac{1}{8}$ |
| $7\frac{1}{2}$ | $12\frac{5}{8}$ | $1\frac{9}{16}$ | $15\frac{5}{8}$ | $5\frac{1}{2}$ | $2\frac{3}{8}$ | $3\frac{7}{8}$ | $1\frac{5}{8}$ | .... | $\frac{9}{16}$ | $1\frac{1}{2}$ | $11\frac{3}{8}$ | $12\frac{1}{2}$ |
| $7\frac{3}{4}$ | 13 | $1\frac{9}{16}$ | 16 | $5\frac{5}{8}$ | $2\frac{3}{8}$ | $3\frac{7}{8}$ | $1\frac{11}{16}$ | .... | $\frac{9}{16}$ | $1\frac{1}{2}$ | $11\frac{3}{4}$ | $12\frac{7}{8}$ |
| 8 | $13\frac{1}{2}$ | $1\frac{5}{8}$ | $16\frac{5}{8}$ | $5\frac{3}{4}$ | $2\frac{1}{2}$ | 4 | $1\frac{3}{4}$ | .... | $\frac{5}{8}$ | $1\frac{1}{2}$ | $12\frac{1}{8}$ | $13\frac{3}{8}$ |
| $8\frac{1}{4}$ | $13\frac{7}{8}$ | $1\frac{5}{8}$ | 17 | $5\frac{7}{8}$ | $2\frac{1}{2}$ | $4\frac{1}{8}$ | $1\frac{13}{16}$ | .... | $\frac{5}{8}$ | $1\frac{5}{8}$ | $12\frac{1}{2}$ | $13\frac{3}{4}$ |
| $8\frac{1}{2}$ | $14\frac{1}{4}$ | $1\frac{3}{4}$ | $17\frac{5}{8}$ | 6 | $2\frac{5}{8}$ | $4\frac{1}{4}$ | $1\frac{13}{16}$ | .... | $\frac{5}{8}$ | $1\frac{5}{8}$ | $12\frac{7}{8}$ | $14\frac{1}{8}$ |
| $8\frac{3}{4}$ | $14\frac{3}{4}$ | $1\frac{3}{4}$ | 18 | $6\frac{1}{4}$ | $2\frac{5}{8}$ | $4\frac{3}{8}$ | $1\frac{7}{8}$ | .... | $\frac{5}{8}$ | $1\frac{5}{8}$ | $13\frac{1}{4}$ | $14\frac{1}{2}$ |
| 9 | $15\frac{1}{8}$ | $1\frac{7}{8}$ | $18\frac{3}{4}$ | $6\frac{3}{8}$ | $2\frac{3}{4}$ | $4\frac{1}{2}$ | $1\frac{15}{16}$ | .... | $\frac{11}{16}$ | $1\frac{3}{4}$ | $13\frac{5}{8}$ | 15 |
| $9\frac{1}{4}$ | $15\frac{1}{2}$ | $1\frac{7}{8}$ | $19\frac{1}{8}$ | $6\frac{1}{2}$ | $2\frac{3}{4}$ | $4\frac{3}{8}$ | 2 | .... | $\frac{11}{16}$ | $1\frac{3}{4}$ | 14 | $15\frac{3}{8}$ |
| $9\frac{1}{2}$ | 16 | $1\frac{15}{16}$ | $19\frac{5}{8}$ | $6\frac{3}{4}$ | $2\frac{7}{8}$ | $4\frac{3}{4}$ | 2 | .... | $\frac{11}{16}$ | $1\frac{3}{4}$ | $14\frac{3}{8}$ | $15\frac{3}{4}$ |
| $9\frac{3}{4}$ | $16\frac{3}{8}$ | $1\frac{15}{16}$ | 20 | $6\frac{7}{8}$ | $2\frac{7}{8}$ | $4\frac{7}{8}$ | $2\frac{1}{16}$ | .... | $\frac{11}{16}$ | $1\frac{7}{8}$ | $14\frac{3}{4}$ | $16\frac{1}{8}$ |
| 10 | $16\frac{3}{4}$ | $2\frac{1}{16}$ | $20\frac{3}{4}$ | 7 | 3 | 5 | $2\frac{1}{8}$ | .... | $\frac{3}{4}$ | $1\frac{7}{8}$ | $15\frac{1}{8}$ | $16\frac{5}{8}$ |
| $10\frac{1}{4}$ | $17\frac{1}{8}$ | $2\frac{1}{16}$ | $21\frac{1}{8}$ | $7\frac{1}{8}$ | 3 | $5\frac{1}{8}$ | $2\frac{3}{16}$ | .... | $\frac{3}{4}$ | $1\frac{7}{8}$ | $15\frac{1}{2}$ | 17 |
| $10\frac{1}{2}$ | $17\frac{1}{2}$ | $2\frac{1}{8}$ | $21\frac{5}{8}$ | $7\frac{1}{4}$ | $3\frac{1}{8}$ | $5\frac{1}{4}$ | $2\frac{1}{4}$ | .... | $\frac{3}{4}$ | $1\frac{7}{8}$ | $15\frac{7}{8}$ | $17\frac{3}{8}$ |
| $10\frac{3}{4}$ | 18 | $2\frac{1}{8}$ | 22 | $7\frac{1}{2}$ | $3\frac{1}{8}$ | $5\frac{3}{8}$ | $2\frac{1}{4}$ | .... | $\frac{3}{4}$ | 2 | $16\frac{1}{4}$ | $17\frac{3}{4}$ |
| 11 | $18\frac{3}{8}$ | $2\frac{1}{4}$ | $22\frac{3}{4}$ | $7\frac{5}{8}$ | $3\frac{1}{4}$ | $5\frac{1}{2}$ | $2\frac{5}{16}$ | .... | $\frac{13}{16}$ | 2 | $16\frac{5}{8}$ | $18\frac{1}{4}$ |
| $11\frac{1}{2}$ | $19\frac{1}{4}$ | $2\frac{5}{16}$ | $23\frac{5}{8}$ | $7\frac{7}{8}$ | $3\frac{3}{8}$ | $5\frac{3}{4}$ | $2\frac{3}{8}$ | .... | $\frac{13}{16}$ | $2\frac{1}{8}$ | $17\frac{3}{8}$ | 19 |
| 12 | 20 | $2\frac{7}{16}$ | $24\frac{3}{4}$ | $8\frac{1}{4}$ | $3\frac{1}{2}$ | 6 | $2\frac{1}{2}$ | .... | $\frac{7}{8}$ | $2\frac{1}{4}$ | $18\frac{1}{8}$ | $19\frac{7}{8}$ |

# LOCK NUTS AND SPLIT PINS

## NAVY DEPARTMENT




| Diam. Bolt | B | C | D | E | F | G | H | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|
| $\frac{1}{2}$ | ... | ... | ... | ... | ... | ... | ... | $\frac{1}{4}$ | $\frac{1}{8}$ | $\frac{1}{4}$ |
| $\frac{9}{16}$ | ... | ... | ... | ... | ... | ... | ... | $\frac{1}{4}$ | $\frac{1}{8}$ | $\frac{5}{16}$ |
| $\frac{5}{8}$ | ... | ... | ... | ... | ... | ... | ... | $\frac{1}{4}$ | $\frac{1}{8}$ | $\frac{5}{16}$ |
| $\frac{3}{4}$ | ... | ... | ... | ... | ... | ... | ... | $\frac{1}{4}$ | $\frac{1}{8}$ | $\frac{3}{16}$ |
| $\frac{7}{8}$ | ... | ... | ... | ... | ... | ... | ... | $\frac{1}{4}$ | $\frac{1}{8}$ | $\frac{7}{16}$ |
| 1 | $2\frac{3}{8}$ | $1\frac{9}{16}$ | $\frac{11}{16}$ | $\frac{1}{2}$ | $1\frac{3}{16}$ | $\frac{3}{8}$ | $\frac{3}{16}$ | $\frac{1}{4}$ | $\frac{1}{8}$ | $\frac{1}{2}$ |
| $1\frac{1}{8}$ | $2\frac{5}{8}$ | $1\frac{3}{4}$ | $\frac{11}{16}$ | $\frac{1}{2}$ | $1\frac{3}{16}$ | $\frac{3}{8}$ | $\frac{3}{16}$ | $\frac{1}{4}$ | $\frac{1}{8}$ | $\frac{9}{16}$ |
| $1\frac{1}{4}$ | $2\frac{13}{16}$ | $1\frac{7}{8}$ | $\frac{3}{4}$ | $\frac{9}{16}$ | $1\frac{5}{16}$ | $\frac{3}{8}$ | $\frac{3}{16}$ | $\frac{3}{8}$ | $\frac{3}{16}$ | $\frac{5}{8}$ |
| $1\frac{3}{8}$ | 3 | $2\frac{1}{8}$ | $\frac{13}{16}$ | $\frac{9}{16}$ | $1\frac{3}{8}$ | $\frac{7}{16}$ | $\frac{3}{16}$ | $\frac{3}{8}$ | $\frac{3}{16}$ | $\frac{11}{16}$ |
| $1\frac{1}{2}$ | $3\frac{1}{4}$ | $2\frac{1}{4}$ | $\frac{13}{16}$ | $\frac{11}{16}$ | $1\frac{1}{2}$ | $\frac{7}{16}$ | $\frac{3}{16}$ | $\frac{3}{8}$ | $\frac{3}{16}$ | $\frac{3}{4}$ |
| $1\frac{5}{8}$ | $3\frac{1}{2}$ | $2\frac{1}{2}$ | $\frac{7}{8}$ | $\frac{3}{4}$ | $1\frac{5}{8}$ | $\frac{7}{16}$ | $\frac{3}{16}$ | $\frac{3}{8}$ | $\frac{3}{16}$ | $\frac{13}{16}$ |
| $1\frac{3}{4}$ | $3\frac{11}{16}$ | $2\frac{5}{8}$ | $\frac{7}{8}$ | $\frac{7}{8}$ | $1\frac{3}{4}$ | $\frac{7}{16}$ | $\frac{3}{16}$ | $\frac{3}{8}$ | $\frac{3}{16}$ | $\frac{7}{8}$ |
| $1\frac{7}{8}$ | $3\frac{7}{8}$ | $2\frac{13}{16}$ | $\frac{15}{16}$ | $\frac{15}{16}$ | $1\frac{7}{8}$ | $\frac{1}{2}$ | $\frac{3}{16}$ | $\frac{3}{8}$ | $\frac{3}{16}$ | $\frac{15}{16}$ |
| 2 | $4\frac{1}{8}$ | 3 | $\frac{15}{16}$ | $1\frac{1}{16}$ | 2 | $\frac{1}{2}$ | $\frac{3}{16}$ | $\frac{7}{16}$ | $\frac{1}{4}$ | 1 |
| $2\frac{1}{4}$ | $4\frac{9}{16}$ | $3\frac{3}{8}$ | 1 | $1\frac{1}{4}$ | $2\frac{1}{4}$ | $\frac{1}{2}$ | $\frac{1}{4}$ | $\frac{7}{16}$ | $\frac{1}{4}$ | $1\frac{1}{8}$ |
| $2\frac{1}{2}$ | 5 | $3\frac{3}{4}$ | $1\frac{1}{8}$ | $1\frac{3}{8}$ | $2\frac{1}{2}$ | $\frac{9}{16}$ | $\frac{1}{4}$ | $\frac{7}{16}$ | $\frac{1}{4}$ | $1\frac{1}{4}$ |
| $2\frac{3}{4}$ | $5\frac{7}{16}$ | $4\frac{1}{8}$ | $1\frac{1}{8}$ | $1\frac{5}{8}$ | $2\frac{3}{4}$ | $\frac{9}{16}$ | $\frac{1}{4}$ | $\frac{1}{2}$ | $\frac{5}{16}$ | $1\frac{3}{8}$ |
| 3 | $5\frac{7}{8}$ | $4\frac{1}{2}$ | $1\frac{1}{4}$ | $1\frac{3}{4}$ | 3 | $\frac{5}{8}$ | $\frac{1}{4}$ | $\frac{1}{2}$ | $\frac{5}{16}$ | $1\frac{1}{2}$ |
| $3\frac{1}{4}$ | $6\frac{3}{8}$ | $4\frac{7}{8}$ | $1\frac{1}{4}$ | 2 | $3\frac{1}{4}$ | $\frac{5}{8}$ | $\frac{5}{16}$ | $\frac{1}{2}$ | $\frac{5}{16}$ | $1\frac{5}{8}$ |
| $3\frac{1}{2}$ | $6\frac{13}{16}$ | $5\frac{1}{4}$ | $1\frac{3}{8}$ | $2\frac{1}{8}$ | $3\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{5}{16}$ | $\frac{1}{2}$ | $\frac{5}{16}$ | $1\frac{3}{4}$ |
| $3\frac{3}{4}$ | $7\frac{1}{4}$ | $5\frac{5}{8}$ | $1\frac{3}{8}$ | $2\frac{3}{8}$ | $3\frac{3}{4}$ | $\frac{3}{4}$ | $\frac{5}{16}$ | $\frac{5}{8}$ | $\frac{3}{8}$ | $1\frac{7}{8}$ |
| 4 | $7\frac{11}{16}$ | 6 | $1\frac{1}{2}$ | $2\frac{1}{2}$ | 4 | $\frac{3}{4}$ | $\frac{5}{16}$ | $\frac{5}{8}$ | $\frac{3}{8}$ | 2 |
| $4\frac{1}{4}$ | $8\frac{1}{8}$ | $6\frac{3}{8}$ | $1\frac{1}{2}$ | $2\frac{3}{4}$ | $4\frac{1}{4}$ | $\frac{3}{4}$ | $\frac{5}{16}$ | $\frac{5}{8}$ | $\frac{3}{8}$ | $2\frac{1}{8}$ |
| $4\frac{1}{2}$ | $8\frac{9}{16}$ | $6\frac{3}{4}$ | $1\frac{5}{8}$ | $2\frac{7}{8}$ | $4\frac{1}{2}$ | $\frac{3}{4}$ | $\frac{3}{8}$ | $\frac{5}{8}$ | $\frac{3}{8}$ | $2\frac{1}{4}$ |
| $4\frac{3}{4}$ | 9 | $7\frac{1}{8}$ | $1\frac{5}{8}$ | $3\frac{1}{8}$ | $4\frac{3}{4}$ | $\frac{7}{8}$ | $\frac{3}{8}$ | $\frac{5}{8}$ | $\frac{3}{8}$ | $2\frac{3}{8}$ |
| 5 | $9\frac{1}{2}$ | $7\frac{1}{2}$ | $1\frac{3}{4}$ | $3\frac{1}{4}$ | 5 | $\frac{7}{8}$ | $\frac{3}{8}$ | $\frac{11}{16}$ | $\frac{7}{16}$ | $2\frac{1}{2}$ |
| $5\frac{1}{4}$ | $9\frac{7}{8}$ | $7\frac{7}{8}$ | $1\frac{3}{4}$ | $3\frac{1}{2}$ | $5\frac{1}{4}$ | $\frac{7}{8}$ | $\frac{3}{8}$ | $\frac{11}{16}$ | $\frac{7}{16}$ | $2\frac{5}{8}$ |
| $5\frac{1}{2}$ | $10\frac{3}{8}$ | $8\frac{1}{4}$ | $1\frac{7}{8}$ | $3\frac{5}{8}$ | $5\frac{1}{2}$ | $\frac{7}{8}$ | $\frac{3}{8}$ | $\frac{11}{16}$ | $\frac{7}{16}$ | $2\frac{3}{4}$ |
| $5\frac{3}{4}$ | $10\frac{13}{16}$ | $8\frac{5}{8}$ | 2 | $3\frac{3}{4}$ | $5\frac{3}{4}$ | 1 | $\frac{3}{8}$ | $\frac{3}{4}$ | $\frac{1}{2}$ | $2\frac{7}{8}$ |
| 6 | $11\frac{1}{4}$ | 9 | 2 | 4 | 6 | 1 | $\frac{7}{16}$ | $\frac{3}{4}$ | $\frac{1}{2}$ | 3 |
| $6\frac{1}{4}$ | $11\frac{11}{16}$ | $9\frac{3}{8}$ | $2\frac{1}{16}$ | $4\frac{3}{16}$ | $6\frac{1}{4}$ | 1 | $\frac{7}{16}$ | $\frac{3}{4}$ | $\frac{1}{2}$ | $3\frac{1}{8}$ |
| $6\frac{1}{2}$ | $12\frac{1}{8}$ | $9\frac{3}{4}$ | $2\frac{1}{8}$ | $4\frac{3}{8}$ | $6\frac{1}{2}$ | 1 | $\frac{7}{16}$ | $\frac{3}{4}$ | $\frac{1}{2}$ | $3\frac{1}{4}$ |
| $6\frac{3}{4}$ | $12\frac{5}{8}$ | $10\frac{1}{8}$ | $2\frac{3}{16}$ | $4\frac{9}{16}$ | $6\frac{3}{4}$ | $1\frac{1}{8}$ | $\frac{7}{16}$ | $\frac{3}{4}$ | $\frac{1}{2}$ | $3\frac{3}{8}$ |

## LOCK NUTS AND SPLIT PINS
*(Continued)*
NAVY DEPARTMENT

| Diam. Bolt | B | C | D | E | F | G | H | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 13 1/16 | 10 1/2 | 2 1/4 | 4 3/4 | 7 | 1 1/8 | 7/16 | 3/4 | 1/2 | 3 1/2 |
| 7 1/4 | 13 1/2 | 10 7/8 | 2 5/16 | 4 15/16 | 7 1/4 | 1 1/8 | 7/16 | 3/4 | 1/2 | 3 5/8 |
| 7 1/2 | 13 15/16 | 11 1/4 | 2 3/8 | 5 1/8 | 7 1/2 | 1 1/8 | 7/16 | 3/4 | 1/2 | 3 3/4 |
| 7 3/4 | 14 3/8 | 11 5/8 | 2 7/16 | 5 5/16 | 7 3/4 | 1 1/4 | 7/16 | 3/4 | 1/2 | 3 7/8 |
| 8 | 14 13/16 | 12 | 2 1/2 | 5 1/2 | 8 | 1 1/4 | 1/2 | 7/8 | 9/16 | 4 |
| 8 1/4 | 15 1/4 | 12 3/8 | 2 9/16 | 5 11/16 | 8 1/4 | 1 1/4 | 1/2 | 7/8 | 9/16 | 4 1/8 |
| 8 1/2 | 15 3/4 | 12 3/4 | 2 5/8 | 5 7/8 | 8 1/2 | 1 1/4 | 1/2 | 7/8 | 9/16 | 4 1/4 |
| 8 3/4 | 16 3/16 | 13 1/8 | 2 11/16 | 6 1/16 | 8 3/4 | 1 3/8 | 1/2 | 7/8 | 9/16 | 4 3/8 |
| 9 | 16 5/8 | 13 1/2 | 2 3/4 | 6 1/4 | 9 | 1 3/8 | 1/2 | 7/8 | 9/16 | 4 1/2 |

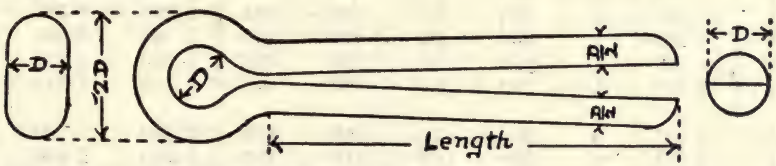
## SPRING COTTERS
NAVY DEPARTMENT

1. **General.**—To be made of high-grade material, of good workmanship, and be free from defects which may affect the serviceability of the cotters.

2. **Material.**—Cotters to be made of either spring brass or spring steel, as specified.

3. **Finish.**—Surface to be finished smooth and the diameter to be uniform. The ends to be slightly rounded, beveled, or pointed to permit easy entering.

4. **Sizes.**—The following table of commercial sizes shows the various lengths for the different diameters:

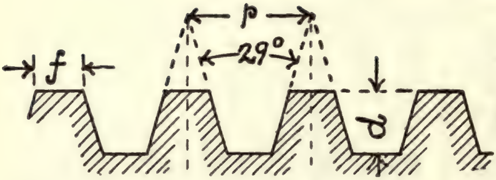



| Diameter, in Inches | Length, in Inches | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3/32 | 1/2 | 3/4 | 1 | 1 1/4 | 1 1/2 | 1 3/4 | 2 | | | | | | | | | |
| 7/64 | 1/2 | 3/4 | 1 | 1 1/4 | 1 1/2 | 1 3/4 | 2 | | | | | | | | | |
| 1/8 | 1/2 | 3/4 | 1 | 1 1/4 | 1 1/2 | 1 3/4 | 2 | 2 1/4 | 2 1/2 | | | | | | | |
| 9/64 | 1/2 | 3/4 | 1 | 1 1/4 | 1 1/2 | 1 3/4 | 2 | 2 1/4 | 2 1/2 | | | | | | | |
| 5/32 | 1/2 | 3/4 | 1 | 1 1/4 | 1 1/2 | 1 3/4 | 2 | 2 1/4 | 2 1/2 | | | | | | | |
| 11/64 | 1/2 | 3/4 | 1 | 1 1/4 | 1 1/2 | 1 3/4 | 2 | 2 1/4 | 2 1/2 | | | | | | | |
| 3/16 | ... | 3/4 | 1 | 1 1/4 | 1 1/2 | 1 3/4 | 2 | 2 1/4 | 2 1/2 | 2 3/4 | 3 | | | | | |
| 13/64 | ... | 3/4 | 1 | 1 1/4 | 1 1/2 | 1 3/4 | 2 | 2 1/4 | 2 1/2 | 2 3/4 | 3 | | | | | |
| 7/32 | ... | ... | 1 | 1 1/4 | 1 1/2 | 1 3/4 | 2 | 2 1/4 | 2 1/2 | 2 3/4 | 3 | | | | | |
| 1/4 | ... | ... | 1 | 1 1/4 | 1 1/2 | 1 3/4 | 2 | 2 1/4 | 2 1/2 | 2 3/4 | 3 | 3 1/2 | 3 3/4 | 4 | | |
| 5/16 | ... | ... | 1 | 1 1/4 | 1 1/2 | 1 3/4 | 2 | 2 1/4 | 2 1/2 | 2 3/4 | 3 | 3 1/2 | 3 3/4 | 4 | | |
| 3/8 | ... | ... | ... | ... | 1 1/2 | 1 3/4 | 2 | 2 1/4 | 2 1/2 | 2 3/4 | 3 | 3 1/2 | 3 3/4 | 4 | | |
| 7/16 | ... | ... | ... | ... | ... | 1 3/4 | 2 | 2 1/4 | 2 1/2 | 2 3/4 | 3 | 3 1/2 | 3 3/4 | 4 | 5 | |
| 1/2 | ... | ... | ... | ... | ... | ... | 2 | 2 1/4 | 2 1/2 | 2 3/4 | 3 | 3 1/2 | 3 3/4 | 4 | 5 | 6 |
| 5/8 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 3 | 3 1/2 | 3 3/4 | 4 | 5 | 6 |

5. **Packing and Marking.**—To be delivered in cardboard boxes containing 50 or 100 cotters each, marked with the name of the material, size, quantity, and name of the manufacturer.

# ACME THREAD SCREWS

## NAVY DEPARTMENT




Formula

$$p = \text{pitch} = \frac{1}{\text{No. threads per in.}}$$

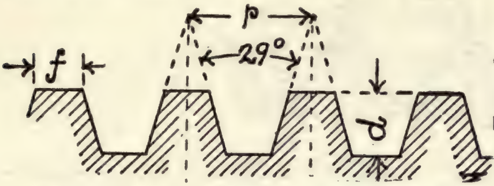
$$d = \text{depth} = \frac{p}{2} \div .010$$

$$f = \text{flat} = p \times .3707$$

| Bolt | | Screw Threads | | | | | | | Nut Depth |
|---|---|---|---|---|---|---|---|---|---|
| Outside Diam. | Area Sq. In. | Threads Per Inch | Pitch p | Depth d | Width of Flat: Top | Width of Flat: Bottom | Diam. at Root of Thread | Effective Area Sq. In. | |
| ½ | 0.196 | 8 | .125 | .073 | .046 | .041 | 0.355 | 0.099 | ⅝ |
| ⅝ | .307 | 7 | .143 | .082 | .053 | .048 | 0.462 | 0.168 | ⅞ |
| ¾ | .442 | 6 | .167 | .094 | .062 | .057 | 0.563 | 0.249 | 1 |
| ⅞ | .601 | 6 | .167 | .094 | .062 | .057 | 0.688 | 0.372 | 1⅛ |
| 1 | .785 | 5 | .200 | .110 | .074 | .069 | 0.780 | 0.478 | 1⅜ |
| 1⅛ | .994 | 5 | .200 | .110 | .074 | .069 | 0.905 | 0.643 | 1½ |
| 1¼ | 1.227 | 4 | .250 | .135 | .093 | .088 | 0.980 | 0.754 | 1⅝ |
| 1⅜ | 1.485 | 4 | .250 | .135 | .093 | .088 | 1.105 | 0.959 | 1¾ |
| 1½ | 1.767 | 4 | .250 | .135 | .093 | .088 | 1.230 | 1.188 | 2 |
| 1⅝ | 2.074 | 4 | .250 | .135 | .093 | .088 | 1.355 | 1.442 | 2⅛ |
| 1¾ | 2.405 | 4 | .250 | .135 | .093 | .088 | 1.480 | 1.720 | 2⅜ |
| 1⅞ | 2.761 | 4 | .250 | .135 | .093 | .088 | 1.605 | 2.023 | 2½ |
| 2 | 3.142 | 4 | .250 | .135 | .093 | .088 | 1.730 | 2.351 | 2¾ |
| 2¼ | 3.976 | 4 | .250 | .135 | .093 | .088 | 1.980 | 3.079 | 3 |
| 2½ | 4.909 | 4 | .250 | .135 | .093 | .088 | 2.230 | 3.906 | 3¼ |
| 2¾ | 5.940 | 4 | .250 | .135 | .093 | .088 | 2.480 | 4.600 | 3⅝ |
| 3 | 7.069 | 4 | .250 | .135 | .093 | .088 | 2.730 | 5.853 | 4 |
| 3¼ | 8.296 | 4 | .250 | .135 | .093 | .088 | 2.980 | 6.975 | 4⅜ |
| 3½ | 9.621 | 4 | .250 | .135 | .093 | .088 | 3.230 | 8.194 | 4⅝ |
| 3¾ | 11.045 | 4 | .250 | .135 | .093 | .088 | 3.480 | 9.511 | 5 |
| 4 | 12.566 | 4 | .250 | .135 | .093 | .088 | 3.730 | 10.927 | 5⅜ |
| 4¼ | 14.186 | 4 | .250 | .135 | .093 | .088 | 3.980 | 12.441 | 5¾ |
| 4½ | 15.904 | 4 | .250 | .135 | .093 | .088 | 4.230 | 14.053 | 6 |
| 4¾ | 17.721 | 4 | .250 | .135 | .093 | .088 | 4.480 | 15.763 | 6⅜ |
| 5 | 19.635 | 4 | .250 | .135 | .093 | .088 | 4.730 | 17.572 | 6¾ |
| 5½ | 23.758 | 4 | .250 | .135 | .093 | .088 | 5.230 | 21.483 | 7⅜ |
| 6 | 28.274 | 4 | .250 | .135 | .093 | .088 | 5.730 | 25.787 | 8⅛ |

# ACME SCREW THREADS

This form of screw thread is much in favor as a substitute for square thread screws required in machine construction.




Formula

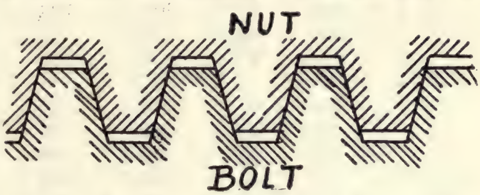
$$p = \text{pitch} = \frac{1}{\text{No. threads per inch}}$$

$$d = \text{depth} = \frac{p}{2} + .010$$

$$f = \text{flat} = p \times .3707$$

Each side of an Acme thread is at an angle of $14\frac{1}{2}°$, or 29° in the included angle between threads. The screw itself is measured by standard, or any given outside diameter suited to the work. Whatever the diameter, the thread in the nut is 0.02 inch over the standard or given diameter, to provide a clearance space at the top of the screw thread; similarly a reduction in diameter of 0.02 is provided at the bottom of the screw thread as clearance for the nut.

The depth of thread is nominally the same as for a square thread screw of equivalent diameter, to which is added 0.01 inch on each side, for clearance. This allowance for clearance at both top and bottom of thread is shown in the accompanying sketch. As compared with a square thread screw, greater strength results from the Acme form of thread because its bottom is much wider than that of a square thread of equal pitch.




**Recapitulation.** — The various parts of the 29° Screw Thread, Acme Standard, are obtained as follows:

Width of point of tool for screw or tap thread $= \dfrac{.3707}{\text{No. of threads per inch}} - .0052.$

Width of screw or nut thread $= \dfrac{.3707}{\text{No. of threads per inch}}$

Diameter of tap = diameter of screw + .020.

Diameter of tap or screw at root =

$$\text{diameter of screw} - \left(\frac{1}{\text{No. of linear threads per inch}} + .020.\right)$$

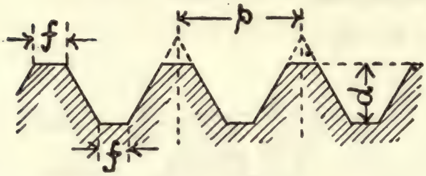
Depth of thread $= \dfrac{1}{2 \times \text{No. of threads per inch}} + .010.$

TABLE OF THREAD PARTS

| No. of Thds. per In. Linear | Depth of Thread | Width at Top of Thread | Width at Bottom of Thread | Space at Top of Thread | Thickness at Root of Thread |
|---|---|---|---|---|---|
| 1 | .5100 | .3707 | .3655 | .6293 | .6345 |
| $1\frac{1}{3}$ | .3850 | .2780 | .2728 | .4720 | .4772 |
| 2 | .2600 | .1853 | .1801 | .3147 | .3199 |
| 3 | .1767 | .1235 | .1183 | .2098 | .2150 |
| 4 | .1350 | .0927 | .0875 | .1573 | .1625 |
| 5 | .1100 | .0741 | .0689 | .1259 | .1311 |
| 6 | .0933 | .0618 | .0566 | .1049 | .1101 |
| 7 | .0814 | .0529 | .0478 | .0899 | .0951 |
| 8 | .0725 | .0463 | .0411 | .0787 | .0839 |
| 9 | .0655 | .0413 | .0361 | .0699 | .0751 |
| 10 | .0600 | .0371 | .0319 | .0629 | .0681 |

# BASTARD THREAD SCREWS

## NAVY DEPARTMENT




| Bolt | | Screw Threads | | | | | | Nut Depth |
|---|---|---|---|---|---|---|---|---|
| Outside Diam. | Area Sq. In. | Threads Per Inch | Pitch p | Depth d | Width f | Diam. at Root of Thread | Effective Area Sq. In. | |
| ½ | 0.196 | 6 | .167 | .083 | .042 | 0.333 | 0.087 | ⅝ |
| ⅝ | .307 | 5 | .200 | .100 | .050 | .425 | .142 | ⅞ |
| ¾ | .442 | 5 | .200 | .100 | .050 | .550 | .238 | 1 |
| ⅞ | .601 | 4½ | .222 | .111 | .056 | .653 | .335 | 1⅛ |
| 1 | .785 | 4 | .250 | .125 | .063 | .750 | .442 | 1⅜ |
| 1⅛ | .994 | 4 | .250 | .125 | .063 | .875 | .601 | 1½ |
| 1¼ | 1.227 | 3½ | .286 | .143 | .071 | .964 | .730 | 1⅝ |
| 1⅜ | 1.485 | 3½ | .286 | .143 | .071 | 1.090 | .933 | 1¾ |
| 1½ | .767 | 3 | .333 | .167 | .083 | 1.167 | 1.070 | 2 |
| 1⅝ | 2.074 | 3 | .333 | .167 | .083 | 1.290 | 1.307 | 2⅛ |
| 1¾ | 2.405 | 3 | .333 | .167 | .083 | 1.417 | 1.577 | 2⅜ |
| 1⅞ | 2.761 | 2½ | .400 | .200 | .100 | 1.475 | 1.709 | 2½ |
| 2 | 3.142 | 2½ | .400 | .200 | .100 | 1.600 | 2.011 | 2¾ |
| 2¼ | 3.976 | 2½ | .400 | .200 | .100 | 1.850 | 2.688 | 3 |
| 2½ | 4.909 | 2 | .500 | .250 | .125 | 2.000 | 3.142 | 3¼ |
| 2¾ | 5.940 | 2 | .500 | .250 | .125 | 2.250 | 3.976 | 3⅝ |
| 3 | 7.069 | 2 | .500 | .250 | .125 | 2.500 | 4.909 | 4 |
| 3¼ | 8.296 | 2 | .500 | .250 | .125 | 2.750 | 5.940 | 4⅜ |
| 3½ | 9.621 | 2 | .500 | .250 | .125 | 3.000 | 7.069 | 4⅝ |
| 3¾ | 11.045 | 2 | .500 | .250 | .125 | 3.250 | 8.296 | 5 |
| 4 | 12.566 | 1½ | .667 | .333 | .167 | 3.335 | 8.736 | 5⅜ |
| 4¼ | 14.186 | 1½ | .667 | .333 | .167 | 3.580 | 10.066 | 5¾ |
| 4½ | 15.904 | 1½ | .667 | .333 | .167 | 3.830 | 11.520 | 6 |
| 4¾ | 17.721 | 1½ | .667 | .333 | .167 | 4.080 | 13.074 | 6⅜ |
| 5 | 19.635 | 1½ | .667 | .333 | .167 | 4.330 | 14.725 | 6¾ |
| 5½ | 23.758 | 1½ | .667 | .333 | .167 | 4.580 | 16.475 | 7⅜ |
| 6 | 28.274 | 1½ | .667 | .333 | .167 | 4.830 | 18.323 | 8⅛ |

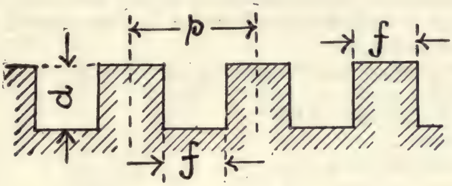
## BASTARD THREAD SCREWS

As the name implies, these screws are somewhat irregular, therefore, difficult of standardization. In general, they serve as substitutes for square thread screws. A coarse pitch of thread gives rapid movement, and the tapering sides of thread facilitate the operation of a closing and disengaging nut.

The proportions are always assumed by the designer, who adapts each screw to the service for which it is intended. The accompanying table, prepared for the use of the Navy Department, is intended to supply its own needs without reference to commercial application.

## SQUARE THREAD SCREWS

NAVY DEPARTMENT




| Bolt | | Screw Threads | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Outside Diam. | Area Sq. In. | Threads per Inch | Pitch P | Depth d | Width f | Diam. at Root of Thread | Effective Area Sq. In. | Nut Depth |
| ½ | 0.196 | 6 | .167 | .083 | .083 | 0.333 | 0.087 | ¾ |
| ⅝ | .307 | 5 | .200 | .100 | .100 | .425 | .142 | 1 |
| ¾ | .442 | 5 | .200 | .100 | .100 | .550 | .238 | 1⅛ |
| ⅞ | .601 | 4½ | .222 | .111 | .111 | .653 | .335 | 1¼ |
| 1 | .785 | 4 | .250 | .125 | .125 | .750 | .442 | 1½ |
| 1⅛ | .994 | 4 | .250 | .125 | .125 | .875 | .601 | 1¾ |
| 1¼ | 1.227 | 3½ | .286 | .143 | .143 | .964 | .730 | 1⅞ |
| 1⅜ | 1.485 | 3½ | .286 | .143 | .143 | 1.090 | .933 | 2 |
| 1½ | 1.767 | 3 | .333 | .167 | .167 | 1.167 | 1.070 | 2¼ |
| 1⅝ | 2.074 | 3 | .333 | .167 | .167 | 1.290 | 1.307 | 2⅜ |
| 1¾ | 2.405 | 3 | .333 | .167 | .167 | 1.417 | 1.577 | 2⅝ |
| 1⅞ | 2.761 | 2½ | .400 | .200 | .200 | 1.475 | 1.709 | 2¾ |
| 2 | 3.142 | 2½ | .400 | .200 | .200 | 1.600 | 2.011 | 3 |
| 2¼ | 3.976 | 2½ | .400 | .200 | .200 | 1.850 | 2.688 | 3⅜ |
| 2½ | 4.909 | 2 | .500 | .250 | .250 | 2.000 | 3.142 | 3¾ |
| 2¾ | 5.940 | 2 | .500 | .250 | .250 | 2.250 | 3.976 | 4⅛ |
| 3 | 7.069 | 2 | .500 | .250 | .250 | 2.500 | 4.909 | 4½ |
| 3¼ | 8.296 | 2 | .500 | .250 | .250 | 2.750 | 5.940 | 4⅞ |
| 3½ | 9.621 | 2 | .500 | .250 | .250 | 3.000 | 7.069 | 5¼ |
| 3¾ | 11.045 | 2 | .500 | .250 | .250 | 3.250 | 8.296 | 5⅝ |
| 4 | 12.566 | 1½ | .667 | .333 | .333 | 3.335 | 8.736 | 6 |
| 4¼ | 14.186 | 1½ | .667 | .333 | .333 | 3.580 | 10.066 | 6⅜ |
| 4½ | 15.904 | 1½ | .667 | .333 | .333 | 3.830 | 11.520 | 6¾ |
| 4¾ | 17.721 | 1½ | .667 | .333 | .333 | 4.080 | 13.074 | 7⅛ |
| 5 | 19.635 | 1½ | .667 | .333 | .333 | 4.330 | 14.725 | 7½ |
| 5½ | 23.758 | 1½ | .667 | .333 | .333 | 4.580 | 16.475 | 8¼ |
| 6 | 28.274 | 1½ | .667 | .333 | .333 | 4.830 | 18.323 | 9 |

# SQUARE THREAD SCREWS

This form of screw thread is much used in machine construction by reason of the large bearing surface presented by the sides of the screw; its coarser pitch, than a standard screw, permits rapid motion to the piece requiring to be moved. The absence of oblique pressure tending to burst a solid nut, or to open a disengaging nut, is in its favor.

The number of threads per inch is commonly half that of a standard screw of the same diameter, but this proportion is not closely followed; see table of Square Thread Screws, Navy Department. The thickness of thread and width of face are generally half the pitch, but this is subject to modification, for the required pitch may be greatly in excess of these proportions.

Rules for square thread screws for ordinary service as given by Unwin are:

$$\text{Pitch} = p = 0.16 + 0.08$$

$$\text{Threads per inch} = n = \frac{1}{p}$$

$$\text{Diameter at bottom of thread} = d_1 = d - \frac{3.8}{n} = 0.85d - 0.075$$

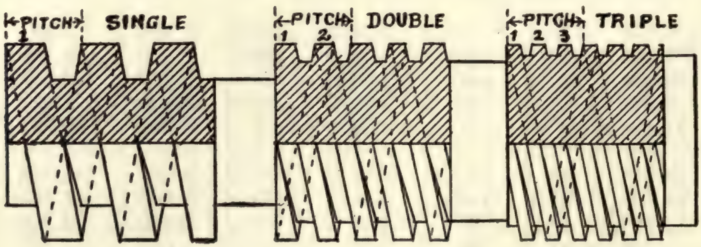
$$\text{Depth of thread} = \frac{19p}{40}$$

To protect the sharp corners of square thread screws from injury, they are sometimes slightly rounded, varying with the amount of protection afforded by the machine in which the screw is to be used. Some designers give the side of thread a slight angle; this facilitates manufacture, as also the entrance of jaws of a disengaging nut.

The bearing pressure allowable on a square thread is subject to wide variation. In general the problem is not one of strength of material, as it is of lubrication. Slow moving screws, intermittent in action, well lubricated, may carry a pressure of 1,000 pounds per square inch. If the service is continuous, the speed moderately high, say 300 feet per minute, the pressure should in no case exceed 150 pounds per square inch of surface contact. Thrust bearin s for torpedo boats are analogous in some respects to square thread screws; the allowable pressure for naval vessels approximates 50 pounds per square inch of collar surface.

# MULTIPLE THREAD SCREWS

Screws having double or triple threads are chiefly used to transmit motion. When the pitch of a screw is required to be much greater than the customary proportions a serious loss of strength may result through an unnecessary reduction of its diameter.

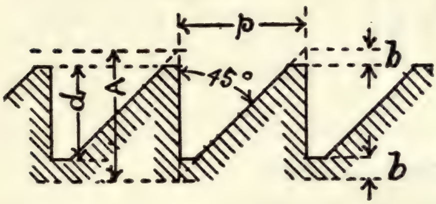



This is overcome in practice by making such a screw double or triple threaded without change of pitch. A deep thread weakens a screw because the effective diameter at root of thread is less than would be the case with a shallow thread. The progressive depths for three screws of the same pitch are shown in the sketch.

## BUTTRESS THREAD SCREWS

This form of screw thread is a modification of both the triangular and square threads; the intent being to combine the smaller friction of a square thread with the greater strength of a triangular thread.

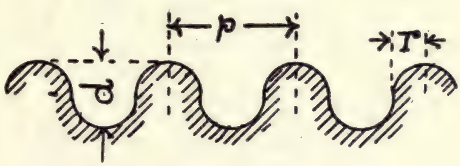
Like the square thread, it has one surface normal to the axis of the screw, and this is the surface which receives the thrust. Designed for resisting a force acting in one direction only, this form of thread is well adapted for breech blocks in heavy ordinance. The shearing strength for a given length of nut is twice that of a square thread.




As to pitch and depth of thread they may follow the tabular dimensions for U. S. standard threads, or, as usually is the case, specially designed for the work. The rear angle of a section of the thread is 45°. Tops and bottoms of threads are cut off and filled in as shown at b in the sketch. In amount b may be one-sixth to one-eighth of the total depth A. If points and roots are not left flat, as in the U. S. threads, they may be slightly rounded, but less in amount than shown for Whitworth threads.

## KNUCKLE THREAD SCREWS

This form of thread is sometimes employed in the manufacture of screw jacks intended for the use of contractors, builders, etc. Screw jacks are commonly subjected to rough usage and receive but little care at best; the excessive rounding of the outer corners of the threads is thought to lessen the possible injury to the screw in service. The half-round bottom of the thread, as shown in the sketch, serves only to make the screw symmetrical in appearance, inasmuch as the bottom of a screw thread is not liable to injury. Threads per inch are commonly the same as for square thread screws of corresponding diameter.

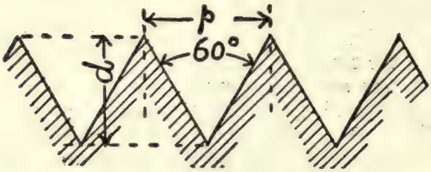



Knuckle Threads

| Diameter in Inches | Threads per Inch | Diameter at Bottom of Thread | Area in Square Inches | | Depth of Nut |
|---|---|---|---|---|---|
| | | | Bottom of Thread | Outside Diameter | |
| 2 | 2½ | 1.60 | 2.01 | 3.14 | 3 |
| 2¼ | 2½ | 1.85 | 2.69 | 3.98 | 3⅜ |
| 2½ | 2 | 2.00 | 3.14 | 4.91 | 3¾ |
| 2¾ | 2 | 2.25 | 3.98 | 5.94 | 4⅛ |
| 3 | 2 | 2.50 | 4.91 | 7.07 | 4½ |
| 3¼ | 2 | 2.75 | 5.94 | 8.30 | 4⅞ |
| 3½ | 2 | 3.00 | 7.07 | 9.62 | 5¼ |
| 3¾ | 2 | 3.25 | 8.30 | 11.05 | 5⅝ |
| 4 | 1½ | 3.34 | 8.74 | 12.57 | 6 |

# SHARP V-THREAD SCREWS

These screws are not in general use and are not standardized. The following table relating to V-thread screws indicates the number of threads per inch for taps and dies meeting ordinary commercial requirements. The dimensions of bolt heads and nuts are Manufacturers' Standard.




Formula

$$p = \text{pitch} = \frac{1}{\text{No. threads per inch.}}$$

$$d = \text{depth} = p \times .866$$

## SHARP V-THREAD SCREWS

This Table is not United States standard

| Diam. Screw A | Thds. per Inch C | Thread Const. | Diam. at Root of Thread B | Square Head and Nut | | | | Hexagon Head and Nut | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Long Diam. E | Short Diam. F | Head Thick. C | Nut Thick. H | Long Diam. | Short Diam. | Head Thick. | Nut Thick. |
| 1/4 | 20 | .0866 | .1634 | 17/32 | 3/8 | 3/16 | 3/16 | 7/16 | 3/8 | 3/16 | 3/16 |
| 5/16 | 18 | .0962 | .2163 | 43/64 | 15/32 | 15/64 | 1/4 | 35/64 | 15/32 | 15/64 | 1/4 |
| 3/8 | 16 | .1083 | .2667 | 51/64 | 9/16 | 9/32 | 5/16 | 21/32 | 9/16 | 9/32 | 5/16 |
| 7/16 | 14 | .1236 | .3139 | 59/64 | 21/32 | 21/64 | 3/8 | 3/4 | 21/32 | 21/64 | 3/8 |
| 1/2 | 12 | .1443 | .3557 | 1 1/16 | 3/4 | 3/8 | 7/16 | 7/8 | 3/4 | 3/8 | 7/16 |
| 9/16 | 12 | .1443 | .4182 | 1 3/32 | 27/32 | 27/64 | 1/2 | 31/32 | 27/32 | 27/64 | 1/2 |
| 5/8 | 11 | .1575 | .4675 | 1 21/64 | 15/16 | 15/32 | 9/16 | 1 3/32 | 15/16 | 15/32 | 9/16 |
| 3/4 | 10 | .1732 | .5768 | 1 19/32 | 1 1/8 | 9/16 | 11/16 | 1 19/64 | 1 1/8 | 9/16 | 11/16 |
| 7/8 | 9 | .1924 | .6826 | 1 55/64 | 1 5/16 | 21/32 | 13/16 | 1 33/64 | 1 5/16 | 21/32 | 13/16 |
| 1 | 8 | .2165 | .7835 | 2 1/8 | 1 1/2 | 3/4 | 15/16 | 1 47/64 | 1 1/2 | 3/4 | 15/16 |
| 1 1/8 | 7 | .2474 | .8776 | 2 25/64 | 1 11/16 | 27/32 | 1 1/8 | 1 61/64 | 1 11/16 | 27/32 | 1 1/8 |
| 1 1/4 | 7 | .2474 | 1.0026 | 2 21/32 | 1 7/8 | 15/16 | 1 1/4 | 2 11/64 | 1 7/8 | 15/16 | 1 1/4 |
| 1 3/8 | 6 | .2887 | 1.0863 | 2 59/64 | 2 1/16 | 1 1/32 | 1 3/8 | 2 25/64 | 2 1/16 | 1 1/32 | 1 3/8 |
| 1 1/2 | 6 | .2887 | 1.2113 | 3 3/16 | 2 1/4 | 1 1/8 | 1 1/2 | 2 39/64 | 2 1/4 | 1 1/8 | 1 1/2 |
| 1 5/8 | 5 | .3465 | 1.2785 | 3 29/64 | 2 7/16 | 1 7/32 | 1 5/8 | 2 13/16 | 2 7/16 | 1 7/32 | 1 5/8 |
| 1 3/4 | 5 | .3465 | 1.4035 | 3 23/32 | 2 5/8 | 1 5/16 | 1 3/4 | 3 1/32 | 2 5/8 | 1 5/16 | 1 3/4 |
| 1 7/8 | 4 1/2 | .3849 | 1.4901 | 3 31/32 | 2 13/16 | 1 13/32 | 1 7/8 | 3 1/4 | 2 13/16 | 1 13/32 | 1 7/8 |
| 2 | 4 1/2 | .3849 | 1.6151 | 4 1/4 | 3 | 1 1/2 | 2 | 3 15/32 | 3 | 1 1/2 | 2 |
| 2 1/8 | 4 1/2 | .3849 | 1.7401 | 4 1/2 | 3 3/16 | 1 19/32 | 2 1/8 | 3 11/16 | 3 3/16 | 1 19/32 | 2 1/8 |
| 2 1/4 | 4 1/2 | .3849 | 1.8651 | 4 25/32 | 3 3/8 | 1 11/16 | 2 1/4 | 3 57/64 | 3 3/8 | 1 11/16 | 2 1/4 |
| 2 3/8 | 4 1/2 | .3849 | 1.9901 | 5 1/32 | 3 9/16 | 1 25/32 | 2 3/8 | 4 7/64 | 3 9/16 | 1 25/32 | 2 3/8 |
| 2 1/2 | 4 | .4330 | 2.0670 | 5 19/64 | 3 3/4 | 1 7/8 | 2 1/2 | 4 11/32 | 3 3/4 | 1 7/8 | 2 1/2 |
| 2 5/8 | 4 | .4330 | 2.1920 | 5 9/16 | 3 15/16 | 1 31/32 | 2 5/8 | 4 35/64 | 3 15/16 | 1 21/32 | 2 5/8 |
| 2 3/4 | 4 | .4330 | 2.3170 | 5 27/32 | 4 1/8 | 2 1/16 | 2 3/4 | 4 49/64 | 4 1/8 | 2 1/16 | 2 3/4 |
| 2 7/8 | 4 | .4330 | 2.442 | 6 3/32 | 4 5/16 | 2 5/32 | 2 7/8 | 4 63/64 | 4 5/16 | 2 5/32 | 2 7/8 |
| 3 | 3 1/2 | .4949 | 2.5051 | 6 23/64 | 4 1/2 | 2 1/4 | 3 | 6 13/64 | 4 1/2 | 2 1/4 | 3 |

# S. A. E. STANDARD SCREWS

The form of screw thread adopted by the Society of Automobile Engineers is the same as in the Franklin Institute Standard, that is, the contained angle of the flat sides of the thread is 60°, with a flat top and flat bottom equal to one-eighth of the pitch. The number of threads per inch is greater than in the Franklin Institute Standard.

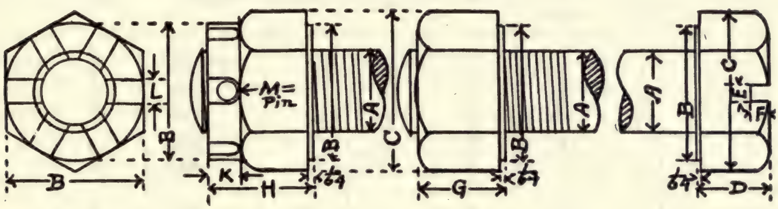
The threaded portion of the bolt equals one and a half times the diameter of screw.

Bolts and nuts to be made of steel, not less than 100,000 pounds tensile strength, with an elastic limit of 60,000 pounds per square inch.

Screw threads, bolt heads, and plain nuts are to be left soft; castle nuts are to be case-hardened.

Standard details and corresponding dimensions relating to head, nut, and castle nut are given in the accompanying illustration and table.

## S. A. E. STANDARD SCREWS

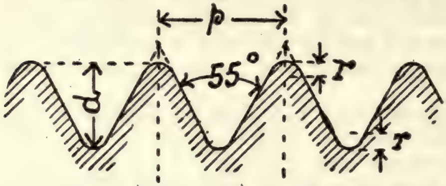



| Screw | | Bolt Head and Nut Details | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Diam. A | Thds. per Inch | B | C | D | E | F | G | H | K | L | M | Diam. Tap Drill |
| $\frac{1}{4}$ | 28 | $\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{3}{16}$ | $\frac{1}{16}$ | $\frac{3}{32}$ | $\frac{7}{32}$ | $\frac{9}{32}$ | $\frac{3}{32}$ | $\frac{5}{64}$ | $\frac{1}{16}$ | $\frac{7}{32}$ |
| $\frac{5}{16}$ | 24 | $\frac{1}{2}$ | $\frac{37}{64}$ | $\frac{15}{64}$ | $\frac{1}{16}$ | $\frac{7}{64}$ | $\frac{17}{64}$ | $\frac{21}{64}$ | $\frac{3}{32}$ | $\frac{5}{64}$ | $\frac{1}{16}$ | $\frac{17}{64}$ |
| $\frac{3}{8}$ | 24 | $\frac{9}{16}$ | $\frac{21}{32}$ | $\frac{9}{32}$ | $\frac{3}{32}$ | $\frac{1}{8}$ | $\frac{21}{64}$ | $\frac{13}{32}$ | $\frac{1}{8}$ | $\frac{1}{8}$ | $\frac{3}{32}$ | $\frac{21}{64}$ |
| $\frac{7}{16}$ | 20 | $\frac{5}{8}$ | $\frac{23}{32}$ | $\frac{21}{64}$ | $\frac{3}{32}$ | $\frac{1}{8}$ | $\frac{3}{8}$ | $\frac{29}{64}$ | $\frac{1}{8}$ | $\frac{1}{8}$ | $\frac{3}{32}$ | $\frac{3}{8}$ |
| $\frac{1}{2}$ | 20 | $\frac{3}{4}$ | $\frac{55}{64}$ | $\frac{3}{8}$ | $\frac{3}{32}$ | $\frac{1}{8}$ | $\frac{7}{16}$ | $\frac{9}{16}$ | $\frac{3}{16}$ | $\frac{1}{8}$ | $\frac{3}{32}$ | $\frac{7}{16}$ |
| $\frac{9}{16}$ | 18 | $\frac{7}{8}$ | $1\frac{1}{64}$ | $\frac{27}{64}$ | $\frac{3}{32}$ | $\frac{1}{8}$ | $\frac{31}{64}$ | $\frac{39}{64}$ | $\frac{3}{16}$ | $\frac{5}{32}$ | $\frac{1}{8}$ | $\frac{1}{2}$ |
| $\frac{5}{8}$ | 18 | $\frac{15}{16}$ | $1\frac{5}{64}$ | $\frac{15}{32}$ | $\frac{3}{32}$ | $\frac{1}{8}$ | $\frac{35}{64}$ | $\frac{23}{32}$ | $\frac{1}{4}$ | $\frac{5}{32}$ | $\frac{1}{8}$ | $\frac{35}{64}$ |
| $\frac{11}{16}$ | 16 | 1 | $1\frac{5}{32}$ | $\frac{33}{64}$ | $\frac{3}{32}$ | $\frac{1}{8}$ | $\frac{19}{32}$ | $\frac{49}{64}$ | $\frac{1}{4}$ | $\frac{5}{32}$ | $\frac{1}{8}$ | $\frac{39}{64}$ |
| $\frac{3}{4}$ | 16 | $1\frac{1}{16}$ | $1\frac{7}{32}$ | $\frac{9}{16}$ | $\frac{3}{32}$ | $\frac{1}{8}$ | $\frac{21}{32}$ | $\frac{13}{16}$ | $\frac{1}{4}$ | $\frac{5}{32}$ | $\frac{1}{8}$ | $\frac{43}{64}$ |
| $\frac{7}{8}$ | 14 | $1\frac{1}{4}$ | $1\frac{7}{16}$ | $\frac{21}{32}$ | $\frac{3}{32}$ | $\frac{1}{8}$ | $\frac{49}{64}$ | $\frac{29}{32}$ | $\frac{1}{4}$ | $\frac{5}{32}$ | $\frac{1}{8}$ | $\frac{25}{32}$ |
| 1 | 14 | $1\frac{7}{16}$ | $1\frac{21}{32}$ | $\frac{3}{4}$ | $\frac{3}{32}$ | $\frac{1}{8}$ | $\frac{7}{8}$ | 1 | $\frac{1}{4}$ | $\frac{5}{32}$ | $\frac{1}{8}$ | $\frac{29}{32}$ |
| $1\frac{1}{8}$ | 12 | $1\frac{5}{8}$ | $1\frac{7}{8}$ | $\frac{27}{32}$ | $\frac{5}{32}$ | $\frac{7}{32}$ | $\frac{63}{64}$ | $1\frac{5}{32}$ | $\frac{5}{16}$ | $\frac{7}{32}$ | $\frac{11}{64}$ | $1\frac{1}{64}$ |
| $1\frac{1}{4}$ | 12 | $1\frac{13}{16}$ | $1\frac{3}{32}$ | $\frac{15}{16}$ | $\frac{5}{32}$ | $\frac{7}{32}$ | $1\frac{3}{32}$ | $1\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{7}{32}$ | $\frac{11}{64}$ | $1\frac{9}{64}$ |
| $1\frac{3}{8}$ | 12 | 2 | $1\frac{5}{16}$ | $1\frac{1}{32}$ | $\frac{3}{16}$ | $\frac{1}{4}$ | $1\frac{13}{64}$ | $1\frac{13}{32}$ | $\frac{3}{8}$ | $\frac{1}{4}$ | $\frac{13}{64}$ | $1\frac{17}{64}$ |
| $1\frac{1}{2}$ | 12 | $2\frac{3}{16}$ | $1\frac{17}{32}$ | $1\frac{1}{8}$ | $\frac{3}{16}$ | $\frac{1}{4}$ | $1\frac{5}{16}$ | $1\frac{1}{2}$ | $\frac{3}{8}$ | $\frac{1}{4}$ | $\frac{13}{64}$ | $1\frac{25}{64}$ |

# WHITWORTH STANDARD THREADS

The form of thread proposed by Sir J. Whitworth and adopted by English engineers is one with flat sides, at an angle to each other of 55°, with a rounded top and bottom. The proportions for the rounded top and bottom are obtained by dividing the depth of a sharp thread having sides of 55° into six equal parts, and within the lines formed by

the sides of the thread and the top and bottom dividing lines, inscribing a circle, which determines the form of top and bottom of thread, thus:




Formula

$$p = \text{pitch} = \frac{1}{\text{No. threads per inch}}$$

$$d = \text{depth} = p \times .6403$$

$$r = \text{radius} = p \times .1373$$

WHITWORTH STANDARD SCREW THREADS, NUTS, AND BOLTS

| Diameter of Bolt | Head and Nut Over | | Height of Nut | Height of Head for Bolts | Threads per Inch | Area at Bottom of Thread | Thick. of Check Nut | Size of Split Pin L. S. G. |
|---|---|---|---|---|---|---|---|---|
| | Flats | Angles | | | | | | |
| $\frac{1}{4}$ | $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{1}{4}$ | $\frac{3}{16}$ | 20 | 0.027 | $\frac{3}{16}$ | No. 14 |
| $\frac{3}{8}$ | $\frac{11}{16}$ | $\frac{13}{16}$ | $\frac{3}{8}$ | $\frac{5}{16}$ | 16 | .068 | $\frac{1}{4}$ | 13 |
| $\frac{1}{2}$ | $\frac{15}{16}$ | $1\frac{1}{16}$ | $\frac{1}{2}$ | $\frac{7}{16}$ | 12 | .121 | $\frac{3}{8}$ | 12 |
| $\frac{5}{8}$ | $1\frac{1}{8}$ | $1\frac{1}{4}$ | $\frac{5}{8}$ | $\frac{9}{16}$ | 11 | .203 | $\frac{7}{16}$ | 11 |
| $\frac{3}{4}$ | $1\frac{5}{16}$ | $1\frac{1}{2}$ | $\frac{3}{4}$ | $\frac{11}{16}$ | 10 | .303 | $\frac{9}{16}$ | 10 |
| $\frac{7}{8}$ | $1\frac{1}{2}$ | $1\frac{11}{16}$ | $\frac{7}{8}$ | $\frac{3}{4}$ | 9 | .421 | $\frac{5}{8}$ | 9 |
| 1 | $1\frac{11}{16}$ | $1\frac{15}{16}$ | 1 | $\frac{7}{8}$ | 8 | .554 | $\frac{3}{4}$ | 8 |
| $1\frac{1}{8}$ | $1\frac{7}{8}$ | $2\frac{1}{8}$ | $1\frac{1}{8}$ | 1 | 7 | .697 | $\frac{13}{16}$ | 7 |
| $1\frac{1}{4}$ | $2\frac{1}{16}$ | $2\frac{3}{8}$ | $1\frac{1}{4}$ | $1\frac{1}{16}$ | 7 | .894 | $\frac{15}{16}$ | 6 |
| $1\frac{3}{8}$ | $2\frac{3}{16}$ | $2\frac{9}{16}$ | $1\frac{3}{8}$ | $1\frac{3}{16}$ | 6 | 1.059 | $1\frac{1}{16}$ | 5 |
| $1\frac{1}{2}$ | $2\frac{7}{16}$ | $2\frac{13}{16}$ | $1\frac{1}{2}$ | $1\frac{5}{16}$ | 6 | 1.300 | $1\frac{1}{8}$ | 4 |
| $1\frac{5}{8}$ | $2\frac{9}{16}$ | 3 | $1\frac{5}{8}$ | $1\frac{7}{16}$ | 5 | 1.471 | $1\frac{1}{4}$ | 3 |
| $1\frac{3}{4}$ | $2\frac{3}{4}$ | $3\frac{3}{16}$ | $1\frac{3}{4}$ | $1\frac{9}{16}$ | 5 | 1.752 | $1\frac{5}{16}$ | 2 |
| $1\frac{7}{8}$ | 3 | $3\frac{1}{2}$ | $1\frac{7}{8}$ | $1\frac{5}{8}$ | $4\frac{1}{2}$ | 1.986 | $1\frac{3}{8}$ | 1 |
| 2 | $3\frac{1}{8}$ | $3\frac{5}{8}$ | 2 | $1\frac{3}{4}$ | $4\frac{1}{2}$ | 2.311 | $1\frac{1}{2}$ | 1 |
| $2\frac{1}{4}$ | $3\frac{9}{16}$ | $4\frac{1}{16}$ | $2\frac{1}{4}$ | 2 | 4 | 2.925 | ... | $\frac{5}{16}$ |
| $2\frac{1}{2}$ | $3\frac{7}{8}$ | $4\frac{1}{2}$ | $2\frac{1}{2}$ | $2\frac{3}{16}$ | 4 | 3.732 | ... | $\frac{5}{16}$ |
| $2\frac{3}{4}$ | $4\frac{3}{16}$ | $4\frac{13}{16}$ | $2\frac{3}{4}$ | $2\frac{7}{16}$ | $3\frac{1}{2}$ | 4.463 | ... | $\frac{3}{8}$ |
| 3 | $4\frac{1}{2}$ | $5\frac{1}{4}$ | 3 | $2\frac{5}{8}$ | $3\frac{1}{2}$ | 5.449 | ... | $\frac{3}{8}$ |
| $3\frac{1}{4}$ | $4\frac{7}{8}$ | $5\frac{5}{8}$ | $3\frac{1}{4}$ | $2\frac{13}{16}$ | $3\frac{1}{4}$ | 6.406 | ... | $\frac{3}{8}$ |
| $3\frac{1}{2}$ | $5\frac{3}{16}$ | 6 | $3\frac{1}{2}$ | $3\frac{1}{16}$ | $3\frac{1}{4}$ | 7.572 | ... | $\frac{7}{16}$ |
| $3\frac{3}{4}$ | $5\frac{9}{16}$ | $6\frac{3}{8}$ | $3\frac{3}{4}$ | $3\frac{1}{4}$ | 3 | 8.656 | ... | $\frac{7}{16}$ |
| 4 | $5\frac{15}{16}$ | $6\frac{7}{8}$ | 4 | $3\frac{1}{2}$ | 3 | 10.026 | ... | $\frac{1}{2}$ |
| $4\frac{1}{4}$ | $6\frac{3}{8}$ | $7\frac{3}{8}$ | $4\frac{1}{4}$ | $3\frac{3}{4}$ | $2\frac{7}{8}$ | 11.370 | ... | $\frac{1}{2}$ |
| $4\frac{1}{2}$ | $6\frac{13}{16}$ | $7\frac{7}{8}$ | $4\frac{1}{2}$ | $3\frac{15}{16}$ | $2\frac{7}{8}$ | 12.913 | ... | $\frac{9}{16}$ |
| $4\frac{3}{4}$ | $7\frac{1}{4}$ | $8\frac{7}{16}$ | $4\frac{3}{4}$ | $4\frac{1}{8}$ | $2\frac{3}{4}$ | 14.413 | ... | $\frac{9}{16}$ |
| 5 | $7\frac{13}{16}$ | 9 | 5 | $4\frac{3}{8}$ | $2\frac{3}{4}$ | 16.145 | ... | $\frac{5}{8}$ |

The above table is from Seaton and Rounthwaite's "Pocket-Book of Marine Engineering," as is also the following table on the strengths of studs and bolts. The table is based on the relation:

Working stress per sq. in. = (Area at bottom of thread)$^{\frac{5}{12}}$ × C; where C = 5,000 for iron or mild steel, and 1,000 for Muntz or gun-metal. For iron or steel bolts above

2 inches diameter, and gun-metal or bronze ones above 3½ inches diameter, the moment of the twisting stress is so small, proportionately, that it may be neglected.

Studs and bolts may be loaded to the figures given in the table whether the load is dead (as in the case of a joint), or live (as in the case of a connecting-rod bolt), as in the latter case mild steel will always be used, and the shearing stress due to tightening up is practically absent.

Mild steel studs and bolts should always be fitted with iron nuts, as steel ones have a much greater tendency to seize, and so greatly increase the twisting stress; for the same reason Muntz metal or naval brass studs should always have iron nuts if possible.

Gun-metal and the various bronzes are unsatisfactory materials for small studs and bolts, not because of any lack of tensile strength—which is often high—but because of their very low elastic limit under a shearing stress.

When iron or steel studs are used in connection with gun-metal steam or water valves, etc., they must not be allowed to penetrate into the steam or water space, or they will rapidly corrode and come loose.

The part of a stud that is screwed into the work should be: Not less than 1¼ diameters long when screwed into cast iron, and 1½ diameters when not inconvenient.

Nor less than 1 diameter long when screwed into gun-metal, wrought iron, or cast steel.

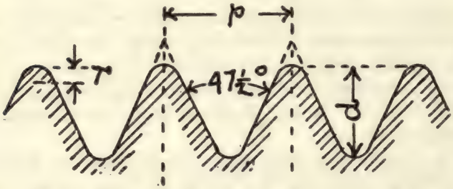
STRENGTH OF STUDS AND BOLTS. WHITWORTH THREADS

| Diameter Stud or Bolt | Iron or Mild Steel | | Muntz or Gun-Metal | |
|---|---|---|---|---|
| | Working Stress in Pounds per Square Inch | Effective Strength of 1 Bolt or Stud in Pounds | Working Stress in Pounds per Square Inch | Effective Strength of 1 Bolt or Stud in Pounds |
| ½ | 2,000 | 250 | 400 | 50 |
| ⅝ | 2,500 | 500 | 500 | 100 |
| ¾ | 3,000 | 900 | 600 | 180 |
| ⅞ | 3,400 | 1,450 | 680 | 290 |
| 1 | 3,900 | 2,150 | 780 | 430 |
| 1⅛ | 4,300 | 3,000 | 860 | 600 |
| 1¼ | 4,700 | 4,200 | 940 | 840 |
| 1⅜ | 5,100 | 5,400 | 1,020 | 1,080 |
| 1½ | 5,500 | 7,100 | 1,100 | 1,420 |
| 1⅝ | 5,800 | 8,500 | 1,160 | 1,700 |
| 1¾ | 6,300 | 11,000 | 1,260 | 2,200 |
| 1⅞ | 6,600 | 13,100 | 1,320 | 2,620 |
| 2 | 7,000 | 16,100 | 1,400 | 3,220 |
| 2¼ | 7,000 | 20,400 | 1,560 | 4,560 |
| 2½ | 7,000 | 26,100 | 1,730 | 6,450 |
| 2¾ | 7,000 | 31,200 | 1,860 | 8,300 |
| 3 | 7,000 | 38,100 | 2,030 | 11,000 |
| 3¼ | 7,000 | 44,800 | 2,170 | 13,900 |
| 3½ | 7,000 | 53,000 | 2,350 | 17,800 |
| 3¾ | 7,000 | 60,500 | 2,500 | 21,600 |
| 4 | 7,000 | 70,100 | 2,500 | 25,000 |
| 4¼ | 7,000 | 79,500 | 2,500 | 28,400 |
| 4½ | 7,000 | 90,300 | 2,500 | 32,200 |
| 4¾ | 7,000 | 100,800 | 2,500 | 36,000 |
| 5 | 7,000 | 113,000 | 2,500 | 40,300 |
| 5¼ | 7,000 | 124,600 | 2,500 | 44,500 |
| 5½ | 7,000 | 138,000 | 2,500 | 49,200 |

## BRITISH ASSOCIATION STANDARD THREAD

This standard has been adopted in England by manufacturers of small screws used by electrical and other instrument makers.

The form of thread is similar to Whitworth's, the angle of the V is $47\frac{1}{2}°$, the top and bottom of threads are rounded off to two-elevenths of the pitch thus:




Formula

$$p = \text{pitch} = \frac{1}{\text{No. thrds. per mm.}}$$

$$d = \text{depth} = p \times .6$$

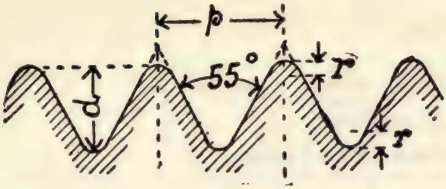
$$r = \text{radius} = \frac{2 \times p}{11}$$

From Unwin: Let d = diameter of screw, and p = pitch in millimeters. Then for screws less than 6 mm. in diameter a series of pitches are assumed $0.9^{0}$, $0.9^{1}$, $0.9^{2}$ . . . and each screw pitch is characterized by a number which is the index of 0.9 in that series. For each of these pitches a standard diameter is selected, given by the equation $d = 6\,p^{\frac{6}{5}}$. The rounding at top and bottom of threads is $\frac{2}{11}$ of the pitch; the depth of thread is $\frac{3}{5}$ of the pitch. The dimensions being in millimeters.

British Association Standard Screw Threads

| Number | Dimensions in Millimeters | | Dimensions in Inches | | Threads per Inch |
|---|---|---|---|---|---|
| | Diameter | Pitch | Diameter | Pitch | |
| 0 | 6.0 | 1.00 | .236 | .0394 | 25.4 |
| 1 | 5.3 | .90 | .209 | .0354 | 28.2 |
| 2 | 4.7 | .81 | .185 | .0319 | 31.4 |
| 3 | 4.1 | .73 | .161 | .0287 | 34.8 |
| 4 | 3.6 | .66 | .142 | .0260 | 38.5 |
| 5 | 3.2 | .59 | .126 | .0232 | 43.0 |
| 6 | 2.8 | .53 | .110 | .0209 | 47.9 |
| 7 | 2.5 | .48 | .098 | .0189 | 52.9 |
| 8 | 2.2 | .43 | .087 | .0169 | 59.1 |
| 9 | 1.9 | .39 | .075 | .0154 | 65.1 |
| 10 | 1.7 | .35 | .067 | .0138 | 72.6 |
| 11 | 1.5 | .31 | .059 | .0122 | 81.9 |
| 12 | 1.3 | .28 | .051 | .0110 | 90.7 |
| 13 | 1.2 | .25 | .047 | .0098 | 101.0 |
| 14 | 1.0 | .23 | .039 | .0091 | 110.0 |
| 15 | .90 | .21 | .035 | .0083 | 121.0 |
| 16 | .79 | .19 | .031 | .0075 | 134.0 |
| 17 | .70 | .17 | .028 | .0067 | 149.0 |
| 18 | .62 | .15 | .024 | .0059 | 169.0 |
| 19 | .54 | .14 | .021 | .0055 | 181.0 |
| 20 | .48 | .12 | .019 | .0047 | 212.0 |
| 21 | .42 | .11 | .017 | .0043 | 231.0 |
| 22 | .37 | .098 | .015 | .0039 | 259.0 |
| 23 | .33 | .089 | .013 | .0035 | 285.0 |
| 24 | .29 | .080 | .011 | .0031 | 317.0 |
| 25 | .25 | .072 | .010 | .0028 | 353.0 |

## INTERNATIONAL STANDARD SCREW THREADS




Formula
$$p = \text{pitch} = \frac{1}{\text{No. threads per inch}}$$
$$d = \text{depth} = p \times .6403$$
$$r = \text{radius} = p \times .1373$$

| Diameter, Inches | Threads per Inch | Diameter, Inches | Threads per Inch | Diameter, Inches | Threads per Inch | Diameter, Inches | Threads per Inch |
|---|---|---|---|---|---|---|---|
| $\frac{1}{4}$ | 25 | $1\frac{1}{8}$ | 9 | 2 | 7 | $3\frac{3}{4}$ | $4\frac{1}{2}$ |
| $\frac{5}{16}$ | 22 | $1\frac{3}{16}$ | 9 | $2\frac{1}{8}$ | 7 | $3\frac{7}{8}$ | $4\frac{1}{2}$ |
| $\frac{3}{8}$ | 20 | $1\frac{1}{4}$ | 9 | $2\frac{1}{4}$ | 6 | 4 | $4\frac{1}{2}$ |
| $\frac{7}{16}$ | 18 | $1\frac{5}{16}$ | 9 | $2\frac{3}{8}$ | 6 | $4\frac{1}{4}$ | 4 |
| $\frac{1}{2}$ | 16 | $1\frac{3}{8}$ | 8 | $2\frac{1}{2}$ | 6 | $4\frac{1}{2}$ | 4 |
| $\frac{9}{16}$ | 16 | $1\frac{7}{16}$ | 8 | $2\frac{5}{8}$ | 6 | $4\frac{3}{4}$ | 4 |
| $\frac{5}{8}$ | 14 | $1\frac{1}{2}$ | 8 | $2\frac{3}{4}$ | 6 | 5 | 4 |
| $\frac{11}{16}$ | 14 | $1\frac{9}{16}$ | 8 | $2\frac{7}{8}$ | 6 | $5\frac{1}{4}$ | $3\frac{1}{2}$ |
| $\frac{3}{4}$ | 12 | $1\frac{5}{8}$ | 8 | 3 | 5 | $5\frac{1}{2}$ | $3\frac{1}{2}$ |
| $\frac{13}{16}$ | 12 | $1\frac{11}{16}$ | 8 | $3\frac{1}{8}$ | 5 | $5\frac{3}{4}$ | $3\frac{1}{2}$ |
| $\frac{7}{8}$ | 11 | $1\frac{3}{4}$ | 7 | $3\frac{1}{4}$ | 5 | 6 | $3\frac{1}{2}$ |
| $\frac{15}{16}$ | 11 | $1\frac{13}{16}$ | 7 | $3\frac{3}{8}$ | 5 | | |
| 1 | 10 | $1\frac{7}{8}$ | 7 | $3\frac{1}{2}$ | $4\frac{1}{2}$ | | |
| $1\frac{1}{16}$ | 10 | $1\frac{15}{16}$ | 7 | $3\frac{5}{8}$ | $4\frac{1}{2}$ | | |

# INTERNATIONAL STANDARD SCREW THREADS

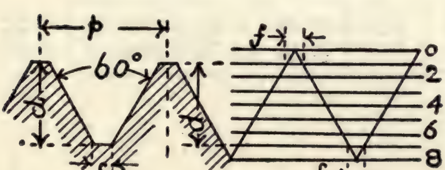
## SYSTEM INTERNATIONAL

The form of thread used is similar to the Franklin Institute Standard; that is, the thread has flat sides, the contained angle between any two threads is 60°; the width of flat at top and bottom of thread is one-eighth of the pitch. A clearance at the bottom of thread—not exceeding one-sixteenth of the height of the original triangle—is included in the specifications—and it is recommended that the clearance occurring at the bottom of the screw shall be rounded. The clearance is obligatory, but the bottom of the screw may or may not be flat, inasmuch as the rounded bottom is left to the discretion of the manufacturer.

This standard differs in some respects from the French Standard, and the later French Standard differs from that formulated by Armengaud.

In the following table the standard dimensions are in terms of the Metric System; English equivalents are supplied in parallel columns for reference only.

International and French Standard Thread—(Metric System)




Formula
$$p = \text{pitch} = \frac{1}{\text{No. threads per inch}}$$
$$d = \text{depth} = p \times .6495$$
$$f = \text{flat} = \frac{p}{8}$$

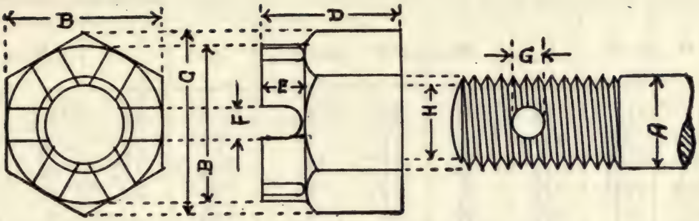
## International Standard Screw Threads

System International

Dimensions in millimeters and inches

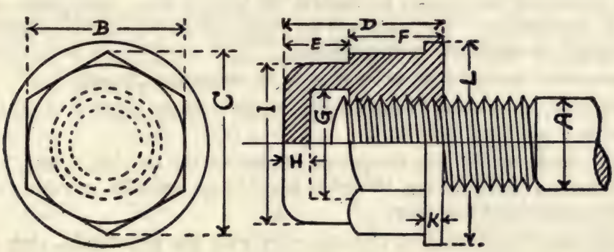
| Outside | | | | Pitch | | Root Diameter | | Root Area | |
|---|---|---|---|---|---|---|---|---|---|
| Diameter | | Area | | | | | | | |
| Mm. | Inches | Mm. | Inches | Mm. | Threads per Inch | Mm. | Inches | Mm. | Inches |
| 3 | 0.1181 | 7.07 | 0.011 | 0.55 | 46.18 | 2.29 | 0.090 | 4.12 | 0.006 |
| 4 | .1575 | 12.57 | .019 | .70 | 36.29 | 3.09 | .122 | 7.50 | .012 |
| 5 | .1968 | 19.63 | .030 | .85 | 29.88 | 3.90 | .153 | 11.95 | .019 |
| 6 | .2362 | 28.27 | .044 | 1.00 | 25.40 | 4.70 | .185 | 17.35 | .027 |
| 7 | .2756 | 38.48 | .060 | 1.00 | 25.40 | 5.70 | .225 | 25.52 | .040 |
| 8 | .3150 | 50.27 | .078 | 1.25 | 20.32 | 6.38 | .251 | 31.97 | .050 |
| 9 | .3543 | 63.62 | .099 | 1.25 | 20.32 | 7.38 | .290 | 42.78 | .066 |
| 10 | .3937 | 78.54 | .122 | 1.50 | 16.93 | 8.05 | .317 | 50.90 | .079 |
| 11 | .4331 | 95.03 | .147 | 1.50 | 16.93 | 9.05 | .356 | 64.33 | 1.100 |
| 12 | .4724 | 113.10 | .175 | 1.75 | 14.51 | 9.73 | .383 | 74.36 | .115 |
| 14 | .5512 | 153.94 | .239 | 2.00 | 12.70 | 11.40 | .449 | 102.07 | .158 |
| 16 | .6299 | 201.06 | .312 | 2.00 | 12.70 | 13.40 | .528 | 141.03 | .219 |
| 18 | .7087 | 254.47 | .394 | 2.50 | 10.16 | 14.75 | .581 | 170.87 | .265 |
| 20 | .7874 | 314.16 | .487 | 2.50 | 10.16 | 16.75 | .660 | 220.35 | .342 |
| 22 | .8661 | 380.13 | .589 | 2.50 | 10.16 | 18.75 | .738 | 276.12 | .428 |
| 24 | .9449 | 452.39 | .701 | 3.00 | 8.47 | 20.10 | .792 | 317.31 | .493 |
| 27 | 1.0630 | 572.56 | .887 | 3.00 | 8.47 | 23.10 | .910 | 419.10 | .650 |
| 30 | 1.1811 | 706.86 | 1.096 | 3.50 | 7.26 | 25.45 | 1.002 | 508.71 | .789 |
| 33 | 1.2992 | 855.30 | 1.326 | 3.50 | 7.26 | 28.45 | 1.120 | 635.70 | .985 |
| 36 | 1.4173 | 1017.88 | 1.578 | 4.00 | 6.35 | 30.80 | 1.213 | 745.06 | 1.155 |
| 39 | 1.5354 | 1194.59 | 1.852 | 4.00 | 6.35 | 33.80 | 1.331 | 897.27 | 1.391 |
| 42 | 1.6535 | 1385.44 | 2.147 | 4.50 | 5.64 | 36.15 | 1.423 | 1026.38 | 1.591 |
| 45 | 1.7716 | 1590.43 | 2.465 | 4.50 | 5.64 | 39.15 | 1.541 | 1203.80 | 1.866 |
| 48 | 1.8898 | 1809.56 | 2.805 | 5.00 | 5.08 | 41.51 | 1.634 | 1353.31 | 2.098 |
| 52 | 2.0472 | 2123.72 | 3.292 | 5.00 | 5.08 | 45.51 | 1.792 | 1626.69 | 2.521 |
| 56 | 2.2047 | 2463.01 | 3.818 | 5.50 | 4.62 | 48.86 | 1.924 | 1874.99 | 2.906 |
| 60 | 2.3622 | 2827.43 | 4.383 | 5.50 | 4.62 | 52.86 | 2.081 | 2194.55 | 3.402 |
| 64 | 2.5197 | 3216.99 | 4.986 | 6.00 | 4.23 | 56.21 | 2.213 | 2481.52 | 3.846 |
| 68 | 2.6772 | 3631.68 | 5.629 | 6.00 | 4.23 | 60.21 | 2.371 | 2847.27 | 4.413 |
| 72 | 2.8346 | 4071.50 | 6.311 | 6.50 | 3.91 | 63.56 | 2.502 | 3172.92 | 4.918 |
| 76 | 2.9921 | 4536.46 | 7.032 | 6.50 | 3.91 | 67.56 | 2.660 | 3584.84 | 5.557 |
| 80 | 3.1497 | 5026.55 | 7.791 | 7.00 | 3.63 | 70.91 | 2.792 | 3949.17 | 6.121 |

## Castle Nuts




| Diam Bolt A | Threads per Inch | Short Diam. B | Long Diam. C | Depth D | Depth E | Width F | Diam. G | Diam. Hole in Blank Nut H |
|---|---|---|---|---|---|---|---|---|
| $\frac{1}{2}$ | 13 | $\frac{7}{8}$ | 1 | $\frac{5}{8}$ | $\frac{7}{32}$ | $\frac{1}{8}$ | $\frac{1}{8}$ | $\frac{25}{64}$ |
| $\frac{9}{16}$ | 12 | $\frac{31}{32}$ | $1\frac{1}{8}$ | $\frac{45}{64}$ | $\frac{1}{4}$ | $\frac{5}{32}$ | $\frac{5}{32}$ | $\frac{29}{64}$ |
| $\frac{5}{8}$ | 11 | $1\frac{1}{16}$ | $1\frac{7}{32}$ | $\frac{25}{32}$ | $\frac{9}{32}$ | $\frac{5}{32}$ | $\frac{5}{32}$ | $\frac{33}{64}$ |
| $\frac{3}{4}$ | 10 | $1\frac{1}{4}$ | $1\frac{7}{16}$ | $\frac{15}{16}$ | $\frac{11}{32}$ | $\frac{3}{16}$ | $\frac{3}{16}$ | $\frac{39}{64}$ |
| $\frac{7}{8}$ | 9 | $1\frac{7}{16}$ | $1\frac{21}{32}$ | $1\frac{3}{32}$ | $\frac{25}{64}$ | $\frac{7}{32}$ | $\frac{7}{32}$ | $\frac{47}{64}$ |
| 1 | 8 | $1\frac{5}{8}$ | $1\frac{7}{8}$ | $1\frac{1}{4}$ | $\frac{7}{16}$ | $\frac{1}{4}$ | $\frac{1}{4}$ | $\frac{53}{64}$ |
| $1\frac{1}{8}$ | 7 | $1\frac{13}{16}$ | $2\frac{3}{32}$ | $1\frac{13}{32}$ | $\frac{1}{2}$ | $\frac{9}{32}$ | $\frac{9}{32}$ | $\frac{59}{64}$ |
| $1\frac{1}{4}$ | 7 | 2 | $2\frac{5}{16}$ | $1\frac{9}{16}$ | $\frac{9}{16}$ | $\frac{5}{16}$ | $\frac{5}{16}$ | $1\frac{1}{16}$ |
| $1\frac{3}{8}$ | 6 | $2\frac{3}{16}$ | $2\frac{17}{32}$ | $1\frac{23}{32}$ | $\frac{39}{64}$ | $\frac{11}{32}$ | $\frac{11}{32}$ | $1\frac{5}{32}$ |
| $1\frac{1}{2}$ | 6 | $2\frac{3}{8}$ | $2\frac{3}{4}$ | $1\frac{7}{8}$ | $\frac{21}{32}$ | $\frac{3}{8}$ | $\frac{3}{8}$ | $1\frac{9}{32}$ |
| $1\frac{5}{8}$ | $5\frac{1}{2}$ | $2\frac{9}{16}$ | $2\frac{31}{32}$ | $2\frac{1}{32}$ | $\frac{23}{32}$ | $\frac{13}{32}$ | $\frac{13}{32}$ | $1\frac{25}{64}$ |
| $1\frac{3}{4}$ | 5 | $2\frac{3}{4}$ | $3\frac{3}{16}$ | $2\frac{5}{16}$ | $\frac{25}{32}$ | $\frac{7}{16}$ | $\frac{7}{16}$ | $1\frac{1}{2}$ |
| $1\frac{7}{8}$ | 5 | $2\frac{15}{16}$ | $3\frac{13}{32}$ | $2\frac{11}{32}$ | $\frac{53}{64}$ | $\frac{15}{32}$ | $\frac{15}{32}$ | $1\frac{5}{8}$ |
| 2 | $4\frac{1}{2}$ | $3\frac{1}{8}$ | $3\frac{19}{32}$ | $2\frac{1}{2}$ | $\frac{7}{8}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{23}{64}$ |
| $2\frac{1}{4}$ | $4\frac{1}{2}$ | $3\frac{1}{2}$ | $4\frac{1}{32}$ | $2\frac{13}{16}$ | 1 | $\frac{9}{16}$ | $\frac{9}{16}$ | $1\frac{21}{32}$ |
| $2\frac{1}{2}$ | 4 | $3\frac{7}{8}$ | $4\frac{15}{32}$ | $3\frac{1}{8}$ | $1\frac{1}{8}$ | $\frac{5}{8}$ | $\frac{5}{8}$ | $1\frac{3}{16}$ |

## Cap Nuts




| A | B | C | D | E | F | G | H | I | K | Diam. Hole U. S. Th. |
|---|---|---|---|---|---|---|---|---|---|---|
| $\frac{1}{2}$ | $\frac{7}{8}$ | 1 | $\frac{7}{8}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $\frac{9}{16}$ | $\frac{5}{32}$ | $\frac{7}{8}$ | $1\frac{1}{8}$ | $\frac{25}{64}$ |
| $\frac{9}{16}$ | $\frac{31}{32}$ | $1\frac{1}{8}$ | 1 | $\frac{7}{16}$ | $\frac{9}{16}$ | $\frac{5}{8}$ | $\frac{5}{32}$ | $\frac{15}{16}$ | $1\frac{1}{4}$ | $\frac{29}{64}$ |
| $\frac{5}{8}$ | $1\frac{1}{16}$ | $1\frac{7}{32}$ | $1\frac{1}{16}$ | $\frac{7}{16}$ | $\frac{5}{8}$ | $\frac{11}{16}$ | $\frac{3}{16}$ | $1\frac{1}{16}$ | $1\frac{3}{8}$ | $\frac{33}{64}$ |
| $\frac{3}{4}$ | $1\frac{1}{4}$ | $1\frac{7}{16}$ | $1\frac{1}{4}$ | $\frac{1}{2}$ | $\frac{3}{4}$ | $\frac{7}{8}$ | $\frac{3}{16}$ | $1\frac{1}{4}$ | $1\frac{5}{8}$ | $\frac{39}{64}$ |
| $\frac{7}{8}$ | $1\frac{7}{16}$ | $1\frac{21}{32}$ | $1\frac{7}{16}$ | $\frac{9}{16}$ | $\frac{7}{8}$ | 1 | $\frac{7}{32}$ | $1\frac{7}{16}$ | $1\frac{13}{16}$ | $\frac{47}{64}$ |

CAP NUTS—(*Continued*)

| A | B | C | D | E | F | G | H | I | K | Diam. Hole U. S. Th. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | $1\frac{5}{8}$ | $1\frac{7}{8}$ | $1\frac{11}{16}$ | $\frac{11}{16}$ | 1 | $1\frac{1}{8}$ | $\frac{1}{4}$ | $1\frac{5}{8}$ | $2\frac{1}{16}$ | $\frac{53}{64}$ |
| $1\frac{1}{8}$ | $1\frac{13}{16}$ | $2\frac{3}{32}$ | $1\frac{7}{8}$ | $\frac{3}{4}$ | $1\frac{1}{8}$ | $1\frac{1}{4}$ | $\frac{1}{4}$ | $1\frac{3}{4}$ | $2\frac{1}{4}$ | $\frac{59}{64}$ |
| $1\frac{1}{4}$ | 2 | $2\frac{5}{16}$ | $2\frac{1}{16}$ | $\frac{13}{16}$ | $1\frac{1}{4}$ | $1\frac{3}{8}$ | $\frac{9}{32}$ | $1\frac{15}{16}$ | $2\frac{1}{2}$ | $1\frac{1}{16}$ |
| $1\frac{3}{8}$ | $2\frac{3}{16}$ | $2\frac{17}{32}$ | $2\frac{1}{4}$ | $\frac{7}{8}$ | $1\frac{3}{8}$ | $1\frac{1}{2}$ | $\frac{9}{32}$ | $2\frac{1}{16}$ | $2\frac{3}{4}$ | $1\frac{5}{32}$ |
| $1\frac{1}{2}$ | $2\frac{3}{8}$ | $2\frac{3}{4}$ | $2\frac{7}{16}$ | $\frac{15}{16}$ | $1\frac{1}{2}$ | $1\frac{11}{16}$ | $\frac{5}{16}$ | $2\frac{5}{16}$ | 3 | $1\frac{9}{32}$ |
| $1\frac{5}{8}$ | $2\frac{9}{16}$ | $2\frac{31}{32}$ | $2\frac{3}{8}$ | 1 | $1\frac{5}{8}$ | $1\frac{13}{16}$ | $\frac{5}{16}$ | $2\frac{7}{16}$ | $3\frac{1}{4}$ | $1\frac{25}{64}$ |
| $1\frac{3}{4}$ | $2\frac{3}{4}$ | $3\frac{3}{16}$ | $2\frac{13}{16}$ | $1\frac{1}{16}$ | $1\frac{3}{4}$ | $1\frac{15}{16}$ | $\frac{11}{32}$ | $2\frac{5}{8}$ | $3\frac{7}{16}$ | $1\frac{1}{2}$ |
| $1\frac{7}{8}$ | $2\frac{15}{16}$ | $3\frac{13}{32}$ | $3\frac{1}{16}$ | $1\frac{3}{16}$ | $1\frac{7}{8}$ | $2\frac{1}{8}$ | $\frac{11}{32}$ | $2\frac{13}{16}$ | $3\frac{11}{16}$ | $1\frac{5}{8}$ |
| 2 | $3\frac{1}{8}$ | $3\frac{19}{32}$ | $3\frac{1}{4}$ | $1\frac{1}{4}$ | 2 | $2\frac{1}{4}$ | $\frac{3}{8}$ | 3 | $3\frac{7}{8}$ | $1\frac{23}{64}$ |

# STEEL BOLTS AND NUTS

## NAVY DEPARTMENT

### BOLTS

Bolts shall be made of a good quality of medium steel, and shall conform to the United States standard for both heads and threads, unless otherwise specified as given in Table I below.

All threads are to be United States standard, and where blanks are not specially called for bolts will be threaded, and nuts will be tapped and fitted thumb-tight to the bolt.

The length of the bolt will be measured from under the head to the first thread at the end of the bolt.

Heads of bolts will be square, hexagonal, or button head, and plain or chamfered, as specified in requisition. The nuts will be square or hexagon, either plain or cupped, or double-cupped, as specified in requisition.

Unless otherwise specified, to be delivered in 100-pound boxes.

All kegs, boxes, or commercial packages to be plainly marked with the manufacturer's name and contract number.

Boxes to be made of new pine or spruce, planed on the outside, $\frac{7}{8}$ inch when finished. Boxes to be exactly 17 inches long, 10 inches high, 11 inches wide, outside measurements, and must be securely put together.

Boxes to be neatly stenciled on one end only with the net weight, size, and name of contents, as:

100 pounds
$\frac{1}{2}$ by $1\frac{1}{2}$ inches
Bolts and nuts, steel
Hexagon heads and nuts.

The manufacturer's name, contract number, and any other marks to be on one side only; one side, one end, top, and bottom to be free from marks.

## TABLE I

### Standard Dimensions of Bolts and Nuts for the United States Navy

| Diameter | | Area | Thrds | Long Diam. | | Short Diam. | Depth | | Diameter of Holes In Blank Nuts |
|---|---|---|---|---|---|---|---|---|---|
| Nom. | Eff. | Eff. | No. | Hex. | Sq. | W. | Head | Nut | |
| $\frac{1}{4}$ | 0.185 | 0.026 | 20 | $\frac{9}{16}$ | $\frac{23}{32}$ | $\frac{1}{2}$ | $\frac{1}{4}$ | $\frac{1}{4}$ | $\frac{3}{16}$ |
| $\frac{5}{16}$ | .240 | .045 | 18 | $\frac{11}{16}$ | $\frac{27}{32}$ | $\frac{19}{32}$ | $\frac{19}{64}$ | $\frac{5}{16}$ | $\frac{1}{4}$ |
| $\frac{3}{8}$ | .294 | .067 | 16 | $\frac{25}{32}$ | $\frac{31}{32}$ | $\frac{11}{16}$ | $\frac{11}{32}$ | $\frac{3}{8}$ | $\frac{19}{64}$ |
| $\frac{7}{16}$ | .345 | .093 | 14 | $\frac{29}{32}$ | $1\frac{3}{32}$ | $\frac{25}{32}$ | $\frac{25}{64}$ | $\frac{7}{16}$ | $\frac{11}{32}$ |
| $\frac{1}{2}$ | .400 | .125 | 13 | 1 | $1\frac{1}{4}$ | $\frac{7}{8}$ | $\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{25}{64}$ |
| $\frac{9}{16}$ | .454 | .162 | 12 | $1\frac{1}{8}$ | $1\frac{3}{8}$ | $\frac{31}{32}$ | $\frac{31}{64}$ | $\frac{9}{16}$ | $\frac{29}{64}$ |
| $\frac{5}{8}$ | .507 | .202 | 11 | $1\frac{7}{32}$ | $1\frac{1}{2}$ | $1\frac{1}{16}$ | $\frac{17}{32}$ | $\frac{5}{8}$ | $\frac{33}{64}$ |
| $\frac{3}{4}$ | .620 | .302 | 10 | $1\frac{7}{16}$ | $1\frac{3}{4}$ | $1\frac{1}{4}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{39}{64}$ |
| $\frac{7}{8}$ | .731 | .419 | 9 | $1\frac{21}{32}$ | $2\frac{1}{32}$ | $1\frac{7}{16}$ | $\frac{23}{32}$ | $\frac{7}{8}$ | $\frac{47}{64}$ |
| 1 | .837 | .550 | 8 | $1\frac{7}{8}$ | $2\frac{5}{16}$ | $1\frac{5}{8}$ | $\frac{13}{16}$ | 1 | $\frac{53}{64}$ |
| $1\frac{1}{8}$ | .940 | .694 | 7 | $2\frac{3}{32}$ | $2\frac{9}{16}$ | $1\frac{13}{16}$ | $\frac{29}{32}$ | $1\frac{1}{8}$ | $\frac{59}{64}$ |
| $1\frac{1}{4}$ | 1.065 | .891 | 7 | $2\frac{5}{16}$ | $2\frac{27}{32}$ | 2 | 1 | $1\frac{1}{4}$ | $1\frac{1}{16}$ |
| $1\frac{3}{8}$ | 1.160 | 1.057 | 6 | $2\frac{17}{32}$ | $3\frac{3}{32}$ | $2\frac{3}{16}$ | $1\frac{3}{32}$ | $1\frac{3}{8}$ | $1\frac{5}{32}$ |
| $1\frac{1}{2}$ | 1.284 | 1.294 | 6 | $2\frac{3}{4}$ | $3\frac{11}{32}$ | $2\frac{3}{8}$ | $1\frac{3}{16}$ | $1\frac{1}{2}$ | $1\frac{9}{32}$ |
| $1\frac{5}{8}$ | 1.389 | 1.515 | $5\frac{1}{2}$ | $2\frac{31}{32}$ | $3\frac{5}{8}$ | $2\frac{9}{16}$ | $1\frac{9}{32}$ | $1\frac{5}{8}$ | $1\frac{25}{64}$ |
| $1\frac{3}{4}$ | 1.491 | 1.746 | 5 | $3\frac{3}{16}$ | $3\frac{7}{8}$ | $2\frac{3}{4}$ | $1\frac{3}{8}$ | $1\frac{3}{4}$ | $1\frac{1}{2}$ |
| $1\frac{7}{8}$ | 1.616 | 2.051 | 5 | $3\frac{13}{32}$ | $4\frac{5}{32}$ | $2\frac{15}{16}$ | $1\frac{15}{32}$ | $1\frac{7}{8}$ | $1\frac{5}{8}$ |
| 2 | 1.712 | 2.302 | $4\frac{1}{2}$ | $3\frac{19}{32}$ | $4\frac{13}{32}$ | $3\frac{1}{8}$ | $1\frac{9}{16}$ | 2 | $1\frac{23}{64}$ |
| $2\frac{1}{4}$ | 1.962 | 3.023 | $4\frac{1}{2}$ | $4\frac{1}{32}$ | $4\frac{15}{16}$ | $3\frac{1}{2}$ | $1\frac{3}{4}$ | $2\frac{1}{4}$ | $1\frac{31}{32}$ |
| $2\frac{1}{2}$ | 2.176 | 3.719 | 4 | $4\frac{15}{32}$ | $5\frac{15}{32}$ | $3\frac{7}{8}$ | $1\frac{15}{16}$ | $2\frac{1}{2}$ | $1\frac{3}{16}$ |
| $2\frac{3}{4}$ | 2.426 | 4.622 | 4 | $4\frac{29}{32}$ | 6 | $4\frac{1}{4}$ | $2\frac{1}{8}$ | $2\frac{3}{4}$ | $2\frac{7}{16}$ |

All bolts 3 inches in diameter and above to have four threads per inch of standard form, except in special cases, which will be submitted for approval.

**Variations of Blank Bolts.**—The variations in size of blank bolts shall not exceed that allowed under Table II below:

## TABLE II

| Nominal Diam. | Maximum Diameter | Minimum Diameter | Maximum Variation | Nominal Diameter | Maximum Diameter | Minimum Diameter | Maximum Variation |
|---|---|---|---|---|---|---|---|
| *Inch* | *Inch* | *Inch* | *Inch* | *Inches* | *Inches* | *Inches* | *Inch* |
| $\frac{3}{16}$ | 0.1925 | 0.1825 | 0.010 | $\frac{15}{16}$ | .9465 | .9285 | 0.018 |
| $\frac{1}{4}$ | .2550 | .245 | .010 | 1 | 1.0095 | .9905 | .019 |
| $\frac{5}{16}$ | .3180 | .307 | .011 | $1\frac{1}{8}$ | 1.1350 | 1.115 | .020 |
| $\frac{3}{8}$ | .3810 | .369 | .012 | $1\frac{1}{4}$ | 1.2605 | 1.2395 | .021 |
| $\frac{7}{16}$ | .444 | .431 | .013 | $1\frac{3}{8}$ | 1.3855 | 1.3645 | .021 |
| $\frac{1}{2}$ | .507 | .493 | .014 | $1\frac{1}{2}$ | 1.5105 | 1.4895 | .021 |
| $\frac{9}{16}$ | .570 | .555 | .015 | $1\frac{5}{8}$ | 1.6355 | 1.6145 | .021 |
| $\frac{5}{8}$ | .633 | .617 | .016 | $1\frac{3}{4}$ | 1.7605 | 1.7395 | .021 |
| $\frac{11}{16}$ | .6955 | .6795 | .016 | $1\frac{7}{8}$ | 1.886 | 1.864 | .022 |
| $\frac{3}{4}$ | .7585 | .7415 | .017 | 2 | 2.011 | 1.989 | .022 |
| $\frac{13}{16}$ | .821 | .804 | .017 | $2\frac{1}{4}$ | 2.261 | 2.239 | .022 |
| $\frac{7}{8}$ | .8840 | .866 | .018 | $2\frac{1}{2}$ | 2.511 | 2.489 | .022 |

**Form and Surface.**—Bolts must be true to form, concentric, and free from scale, fins, seams, and all other injurious or unsightly defects.

**Tests.**—A number of bolts, at the discretion of the inspector, will be taken from each size of each delivery, enough to satisfy the inspector as to the quality of the entire lot, and will be subjected to the following tests:

One-half of these bolts shall be bent cold on unthreaded portion through 180° around a diameter equal to one-half the diameter of the bolts, and they must stand this test without breaking, and only a slight fracture of the skin on one side will be allowed.

The remainder of the bolts will be tested hot. They will be heated to redness and hammered out flat to one-half their original thickness. They will then be reheated to redness and bent around flat to an angle of 180°, and they must stand this test without breaking off.

When bolts are not of sufficient length in the plain part to admit of being bent cold, the threaded part must stand bending cold without fracture as follows:

| | |
|---|---|
| If of ½ inch diameter or less | 35° |
| If above ½ inch diameter and under 1 inch | 30 |
| If 1 inch diameter or over | 25 |

**Bolts and Nuts Ordered Together.**—When bolts and nuts are ordered together the nuts shall conform to the requirements for medium steel or wrought-iron nuts, as stated hereinafter. The threads must be clean and sharp; the nuts must fit thumb-tight, and be delivered on bolts.

## NUTS

Nuts shall be hot pressed or cold punched and of a good quality of medium steel or wrought iron. They shall conform, unless otherwise specified, to the United States standard dimensions as given in Table I under "Bolts." The allowable variations from these dimensions shall not exceed those given in Table II. When nuts are ordered separately they shall be threaded unless otherwise specified in the contract.

**Form and Surface.**—Nuts shall be true to form, concentric, and free from scale, fins, seams, and all other injurious or unsightly defects.

**Hammer Test.**—A number of nuts, at the discretion of the inspector, to be taken from each size of each delivery, enough to satisfy the inspector as to the quality of the entire lot.

One-half of these shall be placed on their sides and hammered out cold, so that they break. The fracture on steel nuts must indicate medium steel of good quality. The fracture in the case of wrought-iron nuts must show the grain to run normally to the plane through the hole.

The remaining nuts shall be heated to redness and hammered under a power hammer to one-sixth their original thickness, and there must be few cracks around the edges, and no signs of large splits or flaws.

## TENSILE TEST OF BOLTS AND NUTS COMBINED

When practicable, tensile test of bolts and nuts combined shall be made. In making the tensile test, the head and nut shall, without previous reduction of sectional area of bolt, be held in opposite jaws of the testing machine and pulled to fracture.

Bolts so tested, to be satisfactory, must in every case fracture at threads, and not at juncture with head, and shall withstand a tensile stress of at least 58,000 pounds, and have an elastic limit of not less than 30,000 pounds per square inch sectional area.

## Bolts and Nuts. Rough Sizes

United States Standard

Weight in pounds per 100 bolts

| Length in Inches | Square Heads and Square Nuts | | | | | Hexagon Heads and Hexagon Nuts | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{7}{8}$ | 1 | $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{7}{8}$ | 1 |
| 2 | 27 | 45 | 67 | 101 | 144 | 24 | 40 | 63 | 93 | 132 |
| $2\frac{1}{2}$ | 30 | 49 | 74 | 109 | 155 | 27 | 45 | 69 | 101 | 143 |
| 3 | 33 | 54 | 80 | 117 | 167 | 30 | 49 | 75 | 109 | 154 |
| $3\frac{1}{2}$ | 35 | 58 | 86 | 126 | 178 | 33 | 54 | 82 | 118 | 165 |
| 4 | 38 | 62 | 92 | 134 | 189 | 35 | 58 | 88 | 126 | 176 |
| $4\frac{1}{2}$ | 41 | 66 | 98 | 142 | 198 | 38 | 62 | 94 | 134 | 186 |
| 5 | 43 | 71 | 104 | 151 | 209 | 41 | 66 | 100 | 143 | 197 |
| $5\frac{1}{2}$ | 46 | 75 | 111 | 159 | 220 | 44 | 71 | 106 | 151 | 208 |
| 6 | 49 | 79 | 117 | 168 | 232 | 46 | 75 | 112 | 160 | 219 |
| $6\frac{1}{2}$ | 52 | 84 | 123 | 176 | 243 | 49 | 79 | 119 | 168 | 230 |
| 7 | 55 | 88 | 129 | 185 | 254 | 52 | 84 | 125 | 177 | 241 |
| $7\frac{1}{2}$ | 57 | 92 | 136 | 193 | 265 | 55 | 88 | 131 | 185 | 252 |
| 8 | 60 | 97 | 142 | 202 | 276 | 58 | 92 | 137 | 194 | 264 |
| $8\frac{1}{2}$ | 63 | 101 | 148 | 210 | 287 | 60 | 96 | 143 | 202 | 274 |
| 9 | 65 | 105 | 154 | 218 | 298 | 63 | 100 | 149 | 210 | 285 |
| $9\frac{1}{2}$ | 68 | 110 | 161 | 227 | 309 | 66 | 105 | 156 | 219 | 296 |
| 10 | 71 | 114 | 167 | 235 | 320 | 68 | 109 | 162 | 227 | 307 |
| $10\frac{1}{2}$ | 74 | 118 | 173 | 244 | 331 | 71 | 114 | 168 | 236 | 318 |
| 11 | 77 | 123 | 180 | 252 | 343 | 74 | 118 | 174 | 244 | 329 |
| $11\frac{1}{2}$ | 79 | 127 | 186 | 261 | 354 | 77 | 122 | 181 | 253 | 341 |
| 12 | 82 | 131 | 192 | 269 | 364 | 80 | 127 | 187 | 261 | 352 |
| 13 | 88 | 140 | 205 | 285 | 387 | 85 | 135 | 199 | 278 | 374 |
| 14 | 93 | 148 | 217 | 303 | 409 | 91 | 144 | 212 | 295 | 396 |
| 15 | 99 | 157 | 230 | 320 | 432 | 96 | 152 | 225 | 312 | 418 |
| 16 | 104 | 165 | 242 | 337 | 451 | 102 | 161 | 237 | 329 | 441 |
| 17 | 110 | 174 | 255 | 354 | 476 | 107 | 170 | 250 | 346 | 463 |
| 18 | 116 | 183 | 267 | 371 | 499 | 113 | 177 | 262 | 364 | 485 |
| 19 | 121 | 192 | 280 | 388 | 521 | 119 | 187 | 275 | 381 | 507 |
| 20 | 127 | 200 | 292 | 405 | 543 | 124 | 196 | 287 | 398 | 530 |
| 21 | 132 | 209 | 305 | 422 | 565 | 130 | 205 | 300 | 415 | 552 |
| 22 | 138 | 218 | 317 | 439 | 588 | 136 | 213 | 313 | 432 | 575 |
| 23 | 143 | 226 | 330 | 456 | 610 | 141 | 222 | 325 | 449 | 597 |
| 24 | 149 | 236 | 342 | 473 | 632 | 147 | 231 | 338 | 466 | 619 |

# MACHINERY BOLTS AND NUTS AND MATERIAL FOR THE SAME

NAVY DEPARTMENT

NOTE.—These specifications are to be used only when finished or semi-finished bolts and nuts are required, as around machinery or for flanges.

1. Machinery bolts and nuts to be of two grades: Semi-finished (faced under head and nut, body trued); finished (machined throughout). Material to be of domestic manufacture. For use on machinery, Class A rods; for minor purposes, Class B rods; for anti-corrosive purposes, rolled naval brass, manganese bronze, or monel metal rods, as stated on the order.

## STEEL RODS

2. The physical and chemical characteristics of steel rods for bolts are to be in accordance with the following table:

| Class | Material | Minimum Tensile Strength | Minimum Elastic Limit | Minimum Elongation[1] | Maximum Amount of— | | Bends[2] |
|---|---|---|---|---|---|---|---|
| | | | | | P. | S. | |
| | | *Pounds per Sq. In.* | *Pounds per Sq. In.* | *Per Cent in 8 Inches* | | | |
| A.... | Open-hearth nickel or carbon steel. | 75,000 | 40,000 | 23 | 0.04 | 0.035 | Cold bend 180° about an inner diameter equal to one-half the thickness of the test piece for diameters up to and including 1 inch, and equal to the thickness for diameters over 1 inch; quench bend 180° about an inner diameter equal to the thickness of the test piece for diameters up to and including 1 inch, and equal to $1\frac{1}{2}$ times the thickness for diameters over 1 inch. |
| B.... | Open-hearth carbon steel. | 58,000 | 30,000 | 28 | 0.04 | 0.035 | Cold bend flat back through 180°; quench bend 180° through an inner diameter equal to one-half the thickness of the test piece for diameters up to and including 1 inch, and equal to the thickness for diameters over 1 inch. |

[1] Elongation for rounds $\frac{1}{2}$ inch and less in diameter shall be measured in an original length equal to 16 times the diameter of the test piece; for material over $\frac{1}{2}$ inch up to and including 1 inch in diameter, the elongation shall be measured in a length of 8 inches; and for material over 1 inch in diameter up to and including 2 inches in diameter, the required percentage of elongation, measured in a length of 8 inches, shall be reduced by one for each increase in diameter of $\frac{1}{4}$ inch or a fraction thereof above 1 inch.

[2] Quench test pieces to be heated to a dark cherry red, as seen in daylight, and plunged into fresh, clean water of 80° to 90° F.

3. If the contractor desires, and so states on his orders, or if inspection at the place of manufacture of the rods is considered impracticable to the bureau concerned, the bureau will direct that the inspection of the rods be made at the place of manufacture of the bolts, instead of at the place where the rods are rolled.

4. **Surface and Other Defects.**—The rods must be true to form, free from seams, hard spots, brittleness, injurious sand, or scale marks, and injurious defects generally.

5. **Tensile Test.**—One tensile-test piece shall be taken from each ton or fraction thereof of rods rolled from the same heat. If, however, the rods in one heat are not of the same diameter, then the inspector will take such additional test pieces as he may consider necessary according to the number of different sizes of rods in the heat. When practicable, but one piece will be cut from each rod selected for the test. Should any test piece be found too large in diameter for the testing machine, the piece may be prepared for test in the manner prescribed for forgings.

6. **Bending Tests.**—If the total weight of the rods rolled from the same heat amounts to 6 tons or more, four cold-bending test pieces and four quench-bending test pieces will be taken; but if the weight is less than 6 tons, one-half that number of test pieces will suffice.

7. **Upsetting Tests.**—From each heat of rounds as rolled there shall be cut six test specimens about 1½ inches long, which shall stand hammering down cold, longitudinally, to one-half their original length without showing seams or other defects which would tend to produce imperfections in the finished product.

## FINISHED BOLTS (CLASSES A AND B)

8. After the rods to be made up into bolts have been tested as previously described, the finished articles shall be tested by lots of 500 pounds or fraction thereof, one piece being taken to represent the lot. The failure of 10 per cent of the lots of 500 pounds to stand the specified tests in a satisfactory manner will render the whole of any delivery liable to rejection.

9. When the bolts are of sufficient length in the plain part to admit of being bent cold, they must stand bending double to a curve of which the inner radius is equal to the radius of the bolt without fracture.

10. When bolts are not of sufficient length in the plain part to admit of being bent cold, the threaded part must stand bending cold without fracture as follows:

| | |
|---|---|
| If of ½ inch diameter or less | 35° |
| If above ½ inch diameter and under 1 inch | 30° |
| If 1 inch diameter or over | 25° |

11. Where the bending tests cannot be applied the two following hammer tests must be substituted:

(a) The test piece to stand flattening out, cold, to a thickness equal to one-half its original diameter without showing cracks.

(b) The test piece to stand flattening out, while heated to a cherry-red heat in daylight, to a thickness equal to one-third its original diameter without showing cracks.

12. (1) All bolts shall be free from surface defects. (2) All bolts are to be headed hot, and the heads made in accordance with the United States standard proportions unless otherwise specified. The head must be concentric with the body of the bolt. (3) The threads must be of the United States standard unless otherwise specified, and must be clean and sharp. The threads of classes A and B bolts may be either chased or cut with a die, but the threads of body-bound bolts must be chased and must extend far enough down so that when the nut is screwed home there will be not more than one and one-half threads under it. The plain part of body-bound bolts must be turned in a lathe to fit accurately in the bolt hole.

## STEEL AND IRON NUTS (TO BE USED WITH CLASSES A AND B BOLTS)

13. One tensile and one bending test bar from each lot of 1,000 pounds of material or less from which nuts are to be made shall be selected by the inspector for test.

14. The material, whether steel or iron, shall show a tensile strength of at least 48,000 pounds per square inch and an elongation of at least 26 per cent in 8 inches. A bar $\frac{1}{2}$ inch square or $\frac{1}{2}$ inch in diameter shall bend back, cold, through an angle of 180° without showing signs of fracture.

15. The nuts must be free from surface defects, and the threads clean, sharp, and well fitting.

16. The dimensions of threads must be in conformity with the United States standard unless otherwise specified.

STANDARD DIMENSIONS OF BOLTS AND NUTS FOR THE UNITED STATES NAVY

| Diameter | | Area | Thrds. | Long Diameter | | Short Diam. | Depth. | | Diameter of Holes in Blank Nuts |
|---|---|---|---|---|---|---|---|---|---|
| Nom. | Eff. | Eff. | No. | Hex. | Sq. | W. | Head | Nut | |
| $\frac{1}{4}$ | 0.185 | 0.026 | 20 | $\frac{9}{16}$ | $\frac{23}{32}$ | $\frac{1}{2}$ | $\frac{1}{4}$ | $\frac{1}{4}$ | $\frac{3}{16}$ |
| $\frac{5}{16}$ | .240 | .045 | 18 | $\frac{11}{16}$ | $\frac{27}{32}$ | $\frac{19}{32}$ | $\frac{19}{64}$ | $\frac{5}{16}$ | $\frac{1}{4}$ |
| $\frac{3}{8}$ | .294 | .067 | 16 | $\frac{25}{32}$ | $\frac{31}{32}$ | $\frac{11}{16}$ | $\frac{11}{32}$ | $\frac{3}{8}$ | $\frac{19}{64}$ |
| $\frac{7}{16}$ | .345 | .093 | 14 | $\frac{29}{32}$ | $1\frac{3}{32}$ | $\frac{25}{32}$ | $\frac{25}{64}$ | $\frac{7}{16}$ | $\frac{11}{32}$ |
| $\frac{1}{2}$ | .400 | .125 | 13 | 1 | $1\frac{1}{4}$ | $\frac{7}{8}$ | $\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{25}{64}$ |
| $\frac{9}{16}$ | .454 | .162 | 12 | $1\frac{1}{8}$ | $1\frac{3}{8}$ | $\frac{31}{32}$ | $\frac{31}{64}$ | $\frac{9}{16}$ | $\frac{29}{64}$ |
| $\frac{5}{8}$ | .507 | .202 | 11 | $1\frac{7}{32}$ | $1\frac{1}{2}$ | $1\frac{1}{16}$ | $\frac{17}{32}$ | $\frac{5}{8}$ | $\frac{33}{64}$ |
| $\frac{3}{4}$ | .620 | .302 | 10 | $1\frac{7}{16}$ | $1\frac{3}{4}$ | $1\frac{1}{4}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{39}{64}$ |
| $\frac{7}{8}$ | .731 | .419 | 9 | $1\frac{21}{32}$ | $2\frac{1}{32}$ | $1\frac{7}{16}$ | $\frac{23}{32}$ | $\frac{7}{8}$ | $\frac{47}{64}$ |
| 1 | .837 | .550 | 8 | $1\frac{7}{8}$ | $2\frac{5}{16}$ | $1\frac{5}{8}$ | $\frac{13}{16}$ | 1 | $\frac{53}{64}$ |
| $1\frac{1}{8}$ | .940 | .694 | 7 | $2\frac{3}{32}$ | $2\frac{9}{16}$ | $1\frac{13}{16}$ | $\frac{29}{32}$ | $1\frac{1}{8}$ | $\frac{59}{64}$ |
| $1\frac{1}{4}$ | 1.065 | .891 | 7 | $2\frac{5}{16}$ | $2\frac{27}{32}$ | 2 | 1 | $1\frac{1}{4}$ | $1\frac{1}{16}$ |
| $1\frac{3}{8}$ | 1.160 | 1.057 | 6 | $2\frac{17}{32}$ | $3\frac{3}{32}$ | $2\frac{3}{16}$ | $1\frac{3}{32}$ | $1\frac{3}{8}$ | $1\frac{5}{32}$ |
| $1\frac{1}{2}$ | 1.284 | 1.294 | 6 | $2\frac{3}{4}$ | $3\frac{11}{32}$ | $2\frac{3}{8}$ | $1\frac{3}{16}$ | $1\frac{1}{2}$ | $1\frac{9}{32}$ |
| $1\frac{5}{8}$ | 1.389 | 1.515 | $5\frac{1}{2}$ | $2\frac{31}{32}$ | $3\frac{5}{8}$ | $2\frac{9}{16}$ | $1\frac{9}{32}$ | $1\frac{5}{8}$ | $1\frac{25}{64}$ |
| $1\frac{3}{4}$ | 1.491 | 1.746 | 5 | $3\frac{3}{16}$ | $3\frac{7}{8}$ | $2\frac{3}{4}$ | $1\frac{3}{8}$ | $1\frac{3}{4}$ | $1\frac{1}{2}$ |
| $1\frac{7}{8}$ | 1.616 | 2.051 | 5 | $3\frac{13}{32}$ | $4\frac{5}{32}$ | $2\frac{15}{16}$ | $1\frac{15}{32}$ | $1\frac{7}{8}$ | $1\frac{5}{8}$ |
| 2 | 1.712 | 2.302 | $4\frac{1}{2}$ | $3\frac{19}{32}$ | $4\frac{13}{32}$ | $3\frac{1}{8}$ | $1\frac{9}{16}$ | 2 | $1\frac{23}{64}$ |
| $2\frac{1}{4}$ | 1.962 | 3.023 | $4\frac{1}{2}$ | $4\frac{1}{32}$ | $4\frac{15}{16}$ | $3\frac{1}{2}$ | $1\frac{3}{4}$ | $2\frac{1}{4}$ | $1\frac{31}{32}$ |
| $2\frac{1}{2}$ | 2.176 | 3.719 | 4 | $4\frac{15}{32}$ | $5\frac{15}{32}$ | $3\frac{7}{8}$ | $1\frac{15}{16}$ | $2\frac{1}{2}$ | $1\frac{3}{16}$ |
| $2\frac{3}{4}$ | 2.426 | 4.622 | 4 | $4\frac{29}{32}$ | 6 | $4\frac{1}{4}$ | $2\frac{1}{8}$ | $2\frac{3}{4}$ | $2\frac{7}{16}$ |

17. The nuts must be hot-pressed or cold-punched, the latter to be reamed before threading, the holes to be central and square with the faces. All nuts must fit on the bolts without shake.

18. Nuts to be used about machinery must fit so tight that it will be necessary to use a wrench to turn them. All other nuts must be at least thumb-tight.

19. For the purpose of test all nuts which fulfil the preceding requirements will be divided into lots of 500 pounds or less, and two nuts from each lot selected by the inspector for test as follows:

(a) One of the two shall stand flattening out, cold, to a thickness equal to one-half its original thickness without showing cracks.

(b) The other shall stand flattening out, when heated to a cherry-red in daylight, to a thickness equal to one-third its original thickness without showing cracks.

20. (a) The failure to stand these tests will subject the lot represented by them to rejection. The failure of 10 per cent of the lot to pass the tests will render the whole order liable to rejection.

## NON-CORROSIVE RODS

21. The composition must be made of such materials as will give the required chemical analysis. Scrap will not be used except such as may result from the process of manufacture of articles of similar composition.

| Letter | Name | Composition by Percentage | | | | | Miscellaneous |
|---|---|---|---|---|---|---|---|
| | | Copper | Tin | Zinc | Lead, Maximum | Iron, Maximum | |
| Mn-r. | Manganese bronze | 57–60 | 0.5–1.5 | 37–40 | ... | 2.5 | Manganese, 0.30. |
| Mo-r. | Monel metal....... | Rem. | ...... | ..... | 0.0 | 3.5 | Nickel, 60 (min.); aluminium, 0.5 (max.). |
| N-r... | Rolled naval brass. | 59–63 | .5–1.5 | Rem. | .2 | .06 | |

22. One test piece for every lot of 400 pounds or less shall show the following results:

| Letter | Name | Ultimate Tensile Strength per Square Inch (Minimum) | Yield Point (Minimum) | Elongation in 2 Inches (Minimum) |
|---|---|---|---|---|
| | | *Pounds* | | *Per Cent* |
| N-r... | Naval brass 1 inch and below............ | 62,000 | ½ ultimate | 25 |
| | Above 1 inch......................... | 60,000 | ½ ultimate | 28 |
| Mn-r. | Manganese bronze, 1 inch and below...... | 72,000 | ½ ultimate | 28 |
| | Above 1 inch......................... | 70,000 | ½ ultimate | 30 |
| Mo-r. | Monel metal, 1 inch and below........... | 84,000 | 47,000 | 25 |
| | Above 1 inch......................... | 80,000 | 45,000 | 28 |

23. If the contractor desires, and so states on his orders, or if inspection at the place of manufacture of the rods is considered impracticable to the bureau concerned, the bureau will direct that the inspection of the rods be made at the place of manufacture of the bolts instead of at the place where the rods are rolled.

24. Test pieces are to be as nearly as possible of the same diameter as the rounds, or else they are to be not less than ½ inch in diameter and taken at a distance from the circumference equal to one-half the radius of the rounds.

25. Test specimens for rounds and bars, or N-r, Mn-r, Mo-r, will stand:

(a) Being hammered hot to a fine point.

(b) Being bent cold through an angle of 120° and to a radius equal to the diameter or thickness of the bars.

(c) The bending bar may be the full-sized bar, or the standard bar of 1 inch width and ½ inch thickness. In the case of bending test pieces of rectangular section, the edges may be rounded off to a radius equal to one-fourth of the thickness.

Fractures of specimens must show throughout uniform color and grain.

26. Various composition materials, otherwise conforming to the specifications, but manufactured under proprietary processes or having proprietary names, will be accepted as rolled naval brass provided the ingredients are approved by the bureau.

27. The rods must be free from all surface defects, clean and straight, of uniform color, quality, and gauge.

28. All requirements of the specifications for steel bolts that are applicable in regard to surface, material, and threading shall apply to non-corrosive bolts.

29. Non-corrosive nuts shall be made of the same material as the bolts.

Note.—All requirements for steel bolts and nuts that are applicable, such as surface, threads, and fitting, shall apply to non-corrosive bolts and nuts.

30. Should it be impracticable for the bureau concerned to inspect the rods before the manufacture of the bolts, the test specified for the stock shall be made on the finished article as far as practicable.

31. **Note for General Storekeepers.**—Requisitions will state the material, size, length over all, whether bolts and nuts are to be semi-finished or finished. If nuts are to be case-hardened, and if nuts are to fit wrench-tight, it will be so noted on the requisition. Length of bolt to be measured from under side of the head to the first thread at the end of bolt. Requisitions should state whether bolts and nuts are to have hexagon heads or square heads.

32. Correspondence relative to interpretation or modification of specifications should be addressed to the bureau concerned, via the naval inspector of material of the district.

## IRON BOLTS AND NUTS

### NAVY DEPARTMENT

NOTE.—This specification to be used only when steel bolts and nuts are considered unsuitable for the purpose.

1. To be of best quality neutral iron and to be bought in three grades, as follows, viz.:

(a) Blanks (not machined).

(b) Semi-finished (face under head and nut, body trued).

(c) Finished (machined throughout).

2. These must conform to the dimensions of the table marked "I," except such small variations as are allowed by the table marked "II." The value of both hexagon and square nuts and heads is compiled from the following:

**Nuts, Blank or Semi-finished.**—D equals one and one-half times diameter of bolt plus $\frac{1}{8}$ inch. B equals diameter of bolt.

**Nuts, Finished.**—D equals one and one-half times diameter of bolt, plus $\frac{1}{16}$ inch. B equals diameter of bolt, less $\frac{1}{16}$ inch.

**Heads, Blank or Semi-finished.**—D equals one and one-half times diameter of bolt, plus $\frac{1}{8}$ inch. B equals one-half short diameter of head.

**Heads, Finished.**—D equals one and one-half times diameter, plus $\frac{1}{16}$ inch. B equals diameter of bolt, less $\frac{1}{16}$ inch.

The long diameter of a hexagon nut may be obtained by multiplying the short diameter by 1.155 and the long diameter of a square nut by multiplying the short diameter by 1.414.

3. All threads are to be United States standard, and, where blanks are not specially called for, bolts will be threaded, and nuts will be tapped and fitted thumb-tight to the bolt to within three threads of the shank.

4. The length of the bolt will be measured from under the head to the first thread at the end of the bolt.

5. Heads of bolts will be square, hexagonal, or button head, and plain or chamfered. The nuts will be square or hexagon, either plain or cupped, or double-cupped. All nuts to be cold punched or hot pressed as required.

6. All kegs, boxes, or commercial packages to be plainly marked with the manufacturer's name.

### MATERIAL AND TEST FOR MACHINE BOLTS AND NUTS OF WROUGHT IRON

1. The material to be known as a good commercial grade of American refined iron.

2. **Tensile Strength.**—Material to be tested in full size when practicable. Specimen bars of not less than $\frac{2}{10}$ square inch sectional area must show an ultimate strength of not less than 48,000 pounds per square inch, and an elongation of not less than 26 per cent in 2 inches.

3. **Test of Bolts.**—From each lot of bolts of the same diameter the inspector will select a sufficient number of test specimens to determine the quality and uniformity of the material used, and the lot will be accepted or rejected according to the results obtained

4. **Fiber Test.**—One-half of the test specimens thus selected shall be nicked with a sharp chisel about 20 per cent of the diameter of the specimen, and bent back flat at this point to an angle of 180°, the fracture showing clean fiber for at least 60 per cent of the area.

5. **Cold Short Test.**—A number of the remaining test specimens shall be bent 180° to a radius of one and one-half times the radius of the hole, without showing a sign of fracture on outer curve.

When the specimens are not of sufficient length in the plain part of the bolt to admit of the above test, the following will be substituted: Break the specimen through the threaded parts without nicking, the result to be the same as required for fiber test.

## TABLE I

| Diameter of Finished Bolt | Nearest Size Drill for Use in Blank. (Blank Nuts Must Not Be Smaller) | Exact Dimensions at Root of Thread | Threads per In. on U.S. Stand. | Hexagon or Square Nuts | | | | Hexagon or Square Heads | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Blank or Semi-finished | | Finished | | Blank or Semi-finished | | Finished | |
| | | | | D | B | D | B | D | B | D | B |
| *Ins.* | *Inches* | *Inches* | | *Inches* | *Inches* | *Inches* | *Inches* | *Inches* | *Inches* | *Inches* | *Inches* |
| $\frac{3}{16}$ | No. 25 | .1469 | 32 | $\frac{13}{32}$ | $\frac{3}{16}$ | $\frac{11}{32}$ | $\frac{1}{8}$ | $\frac{13}{32}$ | $\frac{13}{64}$ | $\frac{11}{32}$ | $\frac{1}{8}$ |
| $\frac{1}{4}$ | $\frac{3}{16}$ | .1850 | 20 | $\frac{1}{2}$ | $\frac{1}{4}$ | $\frac{7}{16}$ | $\frac{3}{16}$ | $\frac{1}{2}$ | $\frac{1}{4}$ | $\frac{7}{16}$ | $\frac{3}{16}$ |
| $\frac{5}{16}$ | $\frac{1}{4}$ | .2403 | 18 | $\frac{19}{32}$ | $\frac{5}{16}$ | $\frac{17}{32}$ | $\frac{1}{4}$ | $\frac{19}{32}$ | $\frac{19}{64}$ | $\frac{17}{32}$ | $\frac{1}{4}$ |
| $\frac{3}{8}$ | $\frac{19}{64}$ | .2936 | 16 | $\frac{11}{16}$ | $\frac{3}{8}$ | $\frac{5}{8}$ | $\frac{5}{16}$ | $\frac{11}{16}$ | $\frac{11}{32}$ | $\frac{5}{8}$ | $\frac{5}{16}$ |
| $\frac{7}{16}$ | $\frac{23}{64}$ | .3447 | 14 | $\frac{25}{32}$ | $\frac{7}{16}$ | $\frac{23}{32}$ | $\frac{3}{8}$ | $\frac{25}{32}$ | $\frac{25}{64}$ | $\frac{23}{32}$ | $\frac{3}{8}$ |
| $\frac{1}{2}$ | $\frac{13}{32}$ | .4001 | 13 | $\frac{7}{8}$ | $\frac{1}{2}$ | $\frac{13}{16}$ | $\frac{7}{16}$ | $\frac{7}{8}$ | $\frac{7}{16}$ | $\frac{13}{16}$ | $\frac{7}{16}$ |
| $\frac{9}{16}$ | $\frac{15}{32}$ | .4542 | 12 | $\frac{31}{32}$ | $\frac{9}{16}$ | $\frac{29}{32}$ | $\frac{1}{2}$ | $\frac{31}{32}$ | $\frac{31}{64}$ | $\frac{29}{32}$ | $\frac{1}{2}$ |
| $\frac{5}{8}$ | $\frac{33}{64}$ | .5069 | 11 | $1\frac{1}{16}$ | $\frac{5}{8}$ | 1 | $\frac{9}{16}$ | $1\frac{1}{16}$ | $\frac{17}{32}$ | 1 | $\frac{9}{16}$ |
| $\frac{11}{16}$ | $\frac{37}{64}$ | .5694 | 11 | $1\frac{5}{32}$ | $\frac{11}{16}$ | $1\frac{3}{32}$ | $\frac{5}{8}$ | $1\frac{5}{32}$ | $\frac{37}{64}$ | $1\frac{3}{32}$ | $\frac{5}{8}$ |
| $\frac{3}{4}$ | $\frac{5}{8}$ | .6201 | 10 | $1\frac{1}{4}$ | $\frac{3}{4}$ | $1\frac{3}{16}$ | $\frac{11}{16}$ | $1\frac{1}{4}$ | $\frac{5}{8}$ | $1\frac{3}{16}$ | $\frac{11}{16}$ |
| $\frac{13}{16}$ | $\frac{11}{16}$ | .6826 | 10 | $1\frac{11}{32}$ | $\frac{13}{16}$ | $1\frac{9}{32}$ | $\frac{3}{4}$ | $1\frac{11}{32}$ | $\frac{43}{64}$ | $1\frac{9}{32}$ | $\frac{3}{4}$ |
| $\frac{7}{8}$ | $\frac{47}{64}$ | .7307 | 9 | $1\frac{7}{16}$ | $\frac{7}{8}$ | $1\frac{3}{8}$ | $\frac{13}{16}$ | $1\frac{7}{16}$ | $\frac{23}{32}$ | $1\frac{3}{8}$ | $\frac{13}{16}$ |
| $\frac{15}{16}$ | $\frac{51}{64}$ | .7932 | 9 | $1\frac{17}{32}$ | $\frac{15}{16}$ | $1\frac{15}{32}$ | $\frac{7}{8}$ | $1\frac{17}{32}$ | $\frac{49}{64}$ | $1\frac{15}{32}$ | $\frac{7}{8}$ |
| 1 | $\frac{27}{32}$ | .8376 | 8 | $1\frac{5}{8}$ | 1 | $1\frac{9}{16}$ | $\frac{15}{16}$ | $1\frac{5}{8}$ | $\frac{13}{16}$ | $1\frac{9}{16}$ | $\frac{15}{16}$ |
| $1\frac{1}{8}$ | $\frac{61}{64}$ | .9394 | 7 | $1\frac{13}{16}$ | $1\frac{1}{8}$ | $1\frac{3}{4}$ | $1\frac{1}{16}$ | $1\frac{13}{16}$ | $\frac{29}{32}$ | $1\frac{3}{4}$ | $1\frac{1}{16}$ |
| $1\frac{1}{4}$ | $1\frac{5}{64}$ | 1.0644 | 7 | 2 | $1\frac{1}{4}$ | $1\frac{15}{16}$ | $1\frac{3}{16}$ | 2 | 1 | $1\frac{15}{16}$ | $1\frac{3}{16}$ |
| $1\frac{3}{8}$ | $1\frac{11}{64}$ | 1.1585 | 6 | $2\frac{3}{16}$ | $1\frac{3}{8}$ | $2\frac{1}{8}$ | $1\frac{5}{16}$ | $2\frac{3}{16}$ | $1\frac{3}{32}$ | $2\frac{1}{8}$ | $1\frac{5}{16}$ |
| $1\frac{1}{2}$ | $1\frac{19}{64}$ | 1.2835 | 6 | $2\frac{3}{8}$ | $1\frac{1}{2}$ | $2\frac{5}{16}$ | $1\frac{7}{16}$ | $2\frac{3}{8}$ | $1\frac{3}{16}$ | $2\frac{5}{16}$ | $1\frac{7}{16}$ |
| $1\frac{5}{8}$ | $1\frac{25}{64}$ | 1.3888 | $5\frac{1}{2}$ | $2\frac{9}{16}$ | $1\frac{5}{8}$ | $2\frac{1}{2}$ | $1\frac{9}{16}$ | $2\frac{9}{16}$ | $1\frac{9}{32}$ | 2 | $1\frac{9}{16}$ |
| $1\frac{3}{4}$ | $1\frac{1}{2}$ | 1.4902 | 5 | $2\frac{3}{4}$ | $1\frac{3}{4}$ | $2\frac{11}{16}$ | $1\frac{11}{16}$ | $2\frac{3}{4}$ | $1\frac{3}{8}$ | $2\frac{11}{16}$ | $1\frac{11}{16}$ |
| $1\frac{7}{8}$ | $1\frac{5}{8}$ | 1.6152 | 5 | $2\frac{15}{16}$ | $1\frac{7}{8}$ | $2\frac{7}{8}$ | $1\frac{13}{16}$ | $2\frac{15}{16}$ | $1\frac{15}{32}$ | $2\frac{7}{8}$ | $1\frac{13}{16}$ |
| 2 | $1\frac{23}{32}$ | 1.7113 | $4\frac{1}{2}$ | $3\frac{1}{8}$ | 2 | $3\frac{1}{16}$ | $1\frac{15}{16}$ | $3\frac{1}{8}$ | $1\frac{9}{16}$ | $3\frac{1}{16}$ | $1\frac{15}{16}$ |
| $2\frac{1}{4}$ | $1\frac{31}{32}$ | 1.9613 | $4\frac{1}{2}$ | $3\frac{1}{2}$ | $2\frac{1}{4}$ | $3\frac{7}{16}$ | $2\frac{3}{16}$ | $3\frac{1}{2}$ | $1\frac{3}{4}$ | $3\frac{7}{16}$ | $2\frac{3}{16}$ |
| $2\frac{1}{2}$ | $2\frac{3}{16}$ | 2.1752 | 4 | $3\frac{7}{8}$ | $2\frac{1}{2}$ | $3\frac{13}{16}$ | $2\frac{7}{16}$ | $3\frac{7}{8}$ | $1\frac{15}{16}$ | $3\frac{13}{16}$ | $2\frac{7}{16}$ |

6. **Hot Test.**—A number of the samples shall be heated to redness and flattened out to one-half the original thickness, and then reheated to red heat and bent to an angle of 180°, and the bend must show no sign of fracture.

7. **Test of Nuts.**—A number of nuts, at the discretion of the inspector, to be taken from each size of each delivery, to determine the quality and uniformity of the material used. The surface of the nuts should be free from defects; the nuts to be of correct

size and proper finish, and the lot will be accepted or rejected according to the results obtained.

8. **Cold Tests.**—A number of nuts, at the discretion of the inspector, shall be tested cold as follows: The nuts shall be placed on their sides and hammered out so they will break; the fracture must show the grain or fiber to run normally to the plane through the hole.

The following table, marked "II," gives the variations in gauge allowed for blank nuts and bolts:

TABLE II

| Nominal Diam. | Maximum Diameter | Minimum Diameter | Maximum Variation | Nominal Diameter | Maximum Diameter | Minimum Diameter | Maximum Variation |
|---|---|---|---|---|---|---|---|
| *Inch* | *Inch* | *Inch* | *Inch* | *Inches* | *Inches* | *Inches* | *Inches* |
| $\frac{3}{16}$ | .1925 | .1825 | 0.010 | $\frac{15}{16}$ | .9465 | .9285 | 0.018 |
| $\frac{1}{4}$ | .2550 | .245 | .010 | 1 | 1.0095 | .9905 | .019 |
| $\frac{5}{16}$ | .3180 | .307 | .011 | $1\frac{1}{8}$ | 1.1350 | 1.115 | .020 |
| $\frac{3}{8}$ | .3810 | .369 | .012 | $1\frac{1}{4}$ | 1.2605 | 1.2395 | .021 |
| $\frac{7}{16}$ | .444 | .431 | .013 | $1\frac{3}{8}$ | 1.3855 | 1.3645 | .021 |
| $\frac{1}{2}$ | .507 | .493 | .014 | $1\frac{1}{2}$ | 1.5105 | 1.4895 | .021 |
| $\frac{9}{16}$ | .570 | .555 | .015 | $1\frac{5}{8}$ | 1.6355 | 1.6145 | .021 |
| $\frac{5}{8}$ | .633 | .617 | .016 | $1\frac{3}{4}$ | 1.7605 | 1.7395 | .021 |
| $\frac{11}{16}$ | .6955 | .6795 | .016 | $1\frac{7}{8}$ | 1.886 | 1.864 | .022 |
| $\frac{3}{4}$ | .7585 | .7415 | .017 | 2 | 2.011 | 1.989 | .022 |
| $\frac{13}{16}$ | .821 | .804 | .017 | $2\frac{1}{4}$ | 2.261 | 2.239 | .022 |
| $\frac{7}{8}$ | .8840 | .866 | .018 | $2\frac{1}{2}$ | 2.511 | 2.489 | .022 |

## DECK BOLTS AND NUTS

### NAVY DEPARTMENT

All deck bolts and nuts to be made of the best quality of neutral iron or mild steel. The bolts shall be well and evenly galvanized to insure a good fit for the nut; to be square necked, with round heads, and to have hexagon nuts, galvanized and fitted thumb-tight to bolts which will be threaded for one-third of their length; bolts and nuts to conform to the following table of dimensions; lengths of bolts to be measured over all:

| Diameter of Bolt | Length of Bolt Over All | Diameter of Head | Thickness of Head | Diameter of Nut | Thickness of Nut |
|---|---|---|---|---|---|
| *Inch* | *Inches* | *Inches* | *Inch* | *Inch* | *Inch* |
| $\frac{1}{2}$ | 3 | 1 | $\frac{3}{16}$ | $\frac{13}{16}$ | $\frac{7}{16}$ |
| $\frac{9}{16}$ | 3 | 1 | $\frac{1}{4}$ | $\frac{29}{32}$ | $\frac{1}{2}$ |
| $\frac{9}{16}$ | $3\frac{1}{2}$ | 1 | $\frac{1}{4}$ | $\frac{29}{32}$ | $\frac{1}{2}$ |
| $\frac{5}{8}$ | 4 | $1\frac{1}{8}$ | $\frac{1}{4}$ | 1 | $\frac{9}{16}$ |

## TESTS OF BOLTS AND NUTS

A number of bolts, at the discretion of the inspector, will be taken from each size of each delivery, enough to satisfy the inspector as to the quality of the entire lot, and will be subjected to the following tests:

1. **Cold Tests.**—One-half of these bolts shall be bent cold through 180° around a diameter equal to one-half the diameter of the bolts, and they must stand this test without breaking, and only a slight fracture of the skin on one side will be allowed.

2. **Hot Test.**—The remainder of the bolts will be tested hot. They will be heated to redness and hammered out flat to one-half their original thickness. They will then be reheated to redness and bent around flat to an angle of 180°, and they must stand this test without breaking off.

# HOLDING-DOWN BOLTS FOR GUN MOUNTS, TORPEDO TUBES, AND TURRET TRACKS

## NAVY DEPARTMENT

1. The "Specifications for Inspection of Steel and Iron Material, General Specifications, Appendix I," issued June, 1912, shall form a part of these specifications, and must be complied with as to material, methods of inspection, and all other requirements therein.

2. Holding-down bolts and their nuts for gun mounts, torpedo tubes, upper and lower turret roller tracks and holding-down clips, shall be made of either forged or rolled bars, and shall conform to the physical and chemical requirements of the following table.

All material shall be free from injurious surface defects and have a workmanlike finish:

| Material | Treatment | Minimum Tensile Strength | Minimum Yield Point | Minimum Elongation in 2" | Maximum Amount of | | Cold Bend Without Cracking |
|---|---|---|---|---|---|---|---|
| | | | | | P. | S. | |
| | | *Lbs. per Sq. In.* | *Lbs. per Sq. In.* | *Per Cent* | *Per Ct.* | *Per Ct.* | |
| O.H. nickel steel. | Annealed, oil tempering optional | 80,000 | 50,000 | 25<br>In 8" 20 Per Cent | .05 | .05 | 180° to inner diameter of ½ inch. |

3. At least two test pieces for tensile test and one test piece for bending shall be tested from different bars from each lot of 50 bars or less made from the same heat and subjected to the same treatment.

4. Finished bolts shall conform also to the following requirements:

(a) Where the bolts are not turned down from the solid rod, but when the rod is upset to form the head, the bolts are to be annealed after such working.

(b) In all cases bolts are to have small fillet under head and not to be cut sharp.

(c) Bolts are to have the head rounded by a radius equal to about 1½ diameters of bolt to insure striking directly over the center of the bolt when driving the same in position.

(d) The United States standard thread to be used unless otherwise ordered; care to be taken that the threads shall be slightly flattened at root and point, as required by said standard.

(e) Threads to be chased, and, in finishing, care to be exercised that the depth of any one cut taken by the finishing tool shall not be sufficient to injure the bolt.

5. Turret-track bolts shall be body-bound turned bolts, with points rounded to radius equal to the diameter of the bolt, and must be a driving fit. The thickness and diameter of turret-track bolt-heads shall be the same as that of the nut; the head to be faced underneath in all cases.

# BOLTS OF STEEL OR COMPOSITION METALS, AND NUTS OF IRON, STEEL, OR COMPOSITION METALS; STUDS AND NUTS AND BARS FOR BOLTS AND NUTS

NAVY DEPARTMENT SPECIFICATIONS

43B9 September 1, 1914

NOTE.—These specifications do not refer to machine bolts and nuts which are covered by Specification 43B5 of latest issue.

1. **General.**—The General Specifications for inspection of material shall form part of these specifications.

## BARS FOR BOLTS AND NUTS

2. **Material.**—The material from which bolts are manufactured shall be medium or commercial steel, rolled naval brass, monel metal, manganese bronze, etc., as may be specified.

3. **Tests of Bars for Steel Bolts when Bars are Ordered.**—To be in accordance with the following requirements:

(a) PHYSICAL AND CHEMICAL CHARACTERISTICS:

| Material | Minimum Tensile Strength | Minimum Yield Point | Minimum Elongation | Maximum Amount of | | Purpose for Which Used |
|---|---|---|---|---|---|---|
| | | | | P. | S. | |
| | *Lbs. per Sq. In.* | *Lbs. per Sq. In.* | *Per Cent in 8 In.*[1] | | | |
| Open-hearth carbon medium steel | 58,000 | 30,000 | 28 | 0.04 | 0.045 | For general structural and machine work. |
| Commercial steel. | ......... | ......... | ......... | ...... | ...... | For miscellaneous work where strength is not important. |

[1] NOTE.—For bars over 1½ inches in diameter add two (2) units of per cent to figures stated for two-inch gauge length and type one test specimen; for bars 1½ inches in diameter or less type three test specimens shall be used.

(b) TENSILE TESTS.—Bars rolled from any melt shall be tested by sizes, two tensile tests to be taken from each ton or less of each size. If the results of such tests from the various sizes indicate that the material is of uniform quality, not more than eight such specimens shall be taken to represent the melt. In such cases the eight specimens shall be fully representative of the various sizes in the melt offered for test. The tensile strengths specified shall be based on the effective sectional area in the threaded portion of the bolt given in Table I.

(c) BENDING TESTS FOR MEDIUM STEEL.—From each size of each melt one cold-bend test shall be taken as finished in the rolls, but not less than two such bends shall be made from any melt. These cold-bend specimens shall be bent 180° flat on themselves without showing any cracks or flaws in the outer round.

## COMPOSITION RODS

4. **General.**—(a) All bars shall be clean and straight, of uniform quality, color, and size, and shall meet the requirements of the latest issue of the leaflet specifications for the material ordered, *i.e.*, rolled manganese bronze, rolled naval brass, rolled monel metal, etc.

(b) Bars will not be tested when bolts are ordered. All tests shall be then be made of the finished product as required by paragraph 6 except when length of bolt is less than three diameters when tests in the bar shall be made.

## MANUFACTURED BOLTS

5. **Material.**—To be manufactured from medium or commercial steel, rolled naval brass rod, rolled manganese bronze rod, rolled monel metal rod, etc., as specified, and shall conform to the following:

6. **Physical Tests.**—(a) Bending.—From each lot of bolts medium steel having the same diameter and ready for final inspection, there will be selected not less than two specimens or one for every 500 pounds or portion thereof. One-half of this number selected shall be bent cold 180° to an inner diameter equal to one-half the diameter of

### TABLE I

Dimensions of Bolts and Nuts

| Nominal Diameter | Number of Threads per Inch | Effective Area of Threaded Portion | Heads: Wrench Width of Square and Hexagonal Head and Diameter of Round Head | Heads: Depth of Head | Nuts: Depth of Nut | Nuts: Wrench Width of Square and Hexagonal Nuts | Diameter at Bottom of Thread of Bolts and of Hole of Blank Nuts |
|---|---|---|---|---|---|---|---|
| a | b | c | d | e | f | g | h |
| *Inches* | | *Sq. In.* | *Inches* | *Inches* | *Inches* | *Inches* | *Inches* |
| $\frac{1}{4}$ | 20 | 0.037 | $\frac{3}{8}$ | $\frac{3}{16}$ | $\frac{3}{16}$ | $\frac{7}{16}$ | 0.185 |
| $\frac{5}{16}$ | 18 | .060 | $\frac{15}{32}$ | $\frac{15}{64}$ | $\frac{1}{4}$ | $\frac{17}{32}$ | .240 |
| $\frac{3}{8}$ | 16 | .088 | $\frac{9}{16}$ | $\frac{9}{32}$ | $\frac{5}{16}$ | $\frac{5}{8}$ | .294 |
| $\frac{7}{16}$ | 14 | .119 | $\frac{21}{32}$ | $\frac{21}{64}$ | $\frac{3}{8}$ | $\frac{23}{32}$ | .344 |
| $\frac{1}{2}$ | 13 | .159 | $\frac{3}{4}$ | $\frac{3}{8}$ | $\frac{7}{16}$ | $\frac{13}{16}$ | .400 |
| $\frac{9}{16}$ | 12 | .203 | $\frac{27}{32}$ | $\frac{27}{64}$ | $\frac{1}{2}$ | $\frac{29}{32}$ | .454 |
| $\frac{5}{8}$ | 11 | .252 | $\frac{15}{16}$ | $\frac{15}{32}$ | $\frac{9}{16}$ | 1 | .507 |
| $\frac{3}{4}$ | 10 | .368 | $1\frac{1}{8}$ | $\frac{9}{16}$ | $\frac{11}{16}$ | $1\frac{3}{16}$ | .620 |
| $\frac{7}{8}$ | 9 | .506 | $1\frac{5}{16}$ | $\frac{21}{32}$ | $\frac{13}{16}$ | $1\frac{3}{8}$ | .731 |
| 1 | 8 | .662 | $1\frac{1}{2}$ | $\frac{3}{4}$ | $\frac{15}{16}$ | $1\frac{9}{16}$ | .837 |
| $1\frac{1}{8}$ | 7 | .836 | $1\frac{11}{16}$ | $\frac{27}{32}$ | $1\frac{1}{8}$ | $1\frac{13}{16}$ | .940 |
| $1\frac{1}{4}$ | 7 | 1.051 | $1\frac{7}{8}$ | $\frac{15}{16}$ | $1\frac{1}{4}$ | 2 | 1.065 |
| $1\frac{3}{8}$ | 6 | 1.261 | $2\frac{1}{16}$ | $1\frac{1}{32}$ | $1\frac{3}{8}$ | $2\frac{3}{16}$ | 1.160 |
| $1\frac{1}{2}$ | 6 | 1.522 | $2\frac{1}{4}$ | $1\frac{1}{8}$ | $1\frac{1}{2}$ | $2\frac{3}{8}$ | 1.284 |
| $1\frac{5}{8}$ | $5\frac{1}{2}$ | 1.784 | $2\frac{7}{16}$ | $1\frac{7}{32}$ | $1\frac{5}{8}$ | $2\frac{9}{16}$ | 1.389 |
| $1\frac{3}{4}$ | 5 | 2.061 | $2\frac{5}{8}$ | $1\frac{5}{16}$ | $1\frac{3}{4}$ | $2\frac{3}{4}$ | 1.491 |
| $1\frac{7}{8}$ | 5 | 2.392 | $2\frac{13}{16}$ | $1\frac{13}{32}$ | $1\frac{7}{8}$ | $2\frac{15}{16}$ | 1.616 |
| 2 | $4\frac{1}{2}$ | 2.705 | 3 | $1\frac{1}{2}$ | 2 | $3\frac{1}{8}$ | 1.712 |
| $2\frac{1}{4}$ | $4\frac{1}{2}$ | 3.483 | $3\frac{3}{8}$ | $1\frac{11}{16}$ | $2\frac{1}{4}$ | $3\frac{1}{2}$ | 1.962 |
| $2\frac{1}{2}$ | 4 | 4.293 | $3\frac{3}{4}$ | $1\frac{7}{8}$ | $2\frac{1}{2}$ | $3\frac{7}{8}$ | 2.176 |
| $2\frac{3}{4}$ | 4 | 5.260 | $4\frac{1}{8}$ | $2\frac{1}{16}$ | $2\frac{3}{4}$ | $4\frac{1}{4}$ | 2.426 |
| | | Formula: $c=.7854\frac{(a+h)^2}{4}$ | Formula: $d=1.5\,a$ | Formula: $e=\frac{d}{2}$ | Up to 1″ $f=a-\frac{1}{16}$; Above 1″ $f=a$ | Up to 1″ $g=d+\frac{1}{16}$; Above 1″ $g=d+\frac{1}{8}$ | |

Note. The dimensions given in Table I are commercial sizes; they are not United States standard.

the bolt, without fracture on the convex side of the bend. If the bolt is too short to permit this test to be made on the unthreaded portion of the shank, the bolt shall be flattened hot to a thickness equal to one-fourth of its diameter and, when cold, this specimen shall be bent 180° flat on itself transversely to the direction of the length of the bolt without fracture.

(b) TENSILE.—The remaining specimens selected as specified in paragraph 6 (a) shall be subject to a tensile tess with the nut in place, unless the length of the bolt is less than three diameters the stress to be applied on the bearing faces of the head and nut. The bolt must meet the tensile strength specified in paragraph 3 (a) and fracture must in all cases occur in the threaded portion of the bolt. Specimens selected for tensile test but which are too short to permit this test to be made must satisfy the bending test specified for short bolts under paragraph 6 (a). Bolts larger than $1\frac{1}{2}$ inches in diameter shall be tested by turning therefrom $1\frac{3}{8}$-inch studs. These studs shall be tested in a like manner as specified for testing bolts by fitting a $1\frac{3}{8}$-inch nut at each end.

7. **Heads.**—The heads will be plain, chamfered, faced on their lower side, or faced and chamfered as specified in the requisition. Chamfering must be at an angle of 30° with the prolongation of the upper face of the head, leaving a circle on its face, whose diameter must be equal to the wrench width as illustrated in the sketch accompanying these specifications. The heads will conform to the dimensions of Table I and must be concentric with the body of the bolt, and square with the body of the bolt.

8. **Dimensions.**—Bolts shall conform to the dimensions given in Table I and shall have United States standard threads. The length of the bolts is to be measured from under the head to the first thread at the point, and to the end of the cylindrical shank in blank bolts.

9. **Threading.**—(a) Unless blanks are specifically called for in the order, the length of the threaded portion of the shank must be in accordance with Table II, if possible, and if not, the shank is to be threaded to the head.

(b) Bolts over 20 inches in length and over $1\frac{1}{4}$ inches in diameter are to be threaded for a length equal to three times the diameter, if not otherwise specified.

(c) Bolts shall be provided, unless otherwise specified, with clean, sharp, and well-fitting United States standard threads, which may be either chased or cut with a die. Nuts to be used on machinery shall fit wrench-tight. Other nuts must be either thumb-tight without shake, or a spinning fit, as specified.

10. **Workmanship.**—Bolts must be hot forged or upset cold; all bolts made by cold upsetting process must be annealed after the heading operation; all bolts must be free from scales, abnormal fins, or other unsightly defects and must have clean, smooth threads, fitting as specified in the requisition.

11. **Finish.**—Bolts will be specified as rough, semi-finished, or finished.

(a) Semi-finished bolts and nuts require machining only on the under side of the bolt-head and nut, and the under side of the head shall face square with the body of the bolt.

## TABLE II

### Length of Threaded Portion of Bolts

| Length of Bolt (Inches) | Diameter of Bolt | | | | | |
|---|---|---|---|---|---|---|
| | 1/4 | 5/16 | 3/8 | 7/16 | 1/2 | 9/16 |
| 1 to 1½..... | 3/4 | 3/4 | 7/8 | 7/8 | 1 | 1 |
| 1⅝ to 2...... | 7/8 | 7/8 | 1 | 1 | 1 | 1 |
| 2⅛ to 2½..... | 1 | 1 | 1 | 1 | 1 | 1 |
| 2⅝ to 3...... | 1 | 1 | 1 | 1 | 1 | 1 |
| 3⅛ to 4...... | 1 | 1 | 1¼ | 1¼ | 1¼ | 1¼ |
| 4⅛ to 8...... | 1 | 1 | 1¼ | 1¼ | 1¼ | 1¼ |
| 8⅛ to 12..... | 1 | 1 | 1¼ | 1¼ | 1½ | 1½ |
| 12⅛ to 20..... | 1 | 1 | 1½ | 1½ | 2 | 2 |

| Length of Bolt (Inches) | Diameter of Bolt | | | | | |
|---|---|---|---|---|---|---|
| | 5/8 | 3/4 | 7/8 | 1 | 1⅛ | 1¼ |
| 1 to 1½..... | 1¼ | .. | .. | .. | .. | .. |
| 1⅝ to 2...... | 1¼ | 1½ | 1¾ | .. | .. | .. |
| 2⅛ to 2½..... | 1¼ | 1½ | 1¾ | 1¾ | .. | .. |
| 2⅝ to 3...... | 1¼ | 1½ | 1¾ | 2 | 2¼ | .. |
| 3⅛ to 4...... | 1½ | 1½ | 1¾ | 2 | 2½ | 2½ |
| 4⅛ to 8...... | 1½ | 1¾ | 2 | 2¼ | 2¾ | 3 |
| 8⅛ to 12..... | 1¾ | 2 | 2¼ | 2½ | 3 | 3¼ |
| 12⅛ to 20..... | 2 | 2 | 2½ | 3 | 3¼ | 3½ |

(b) Finished bolts and nuts require machining throughout.

12. **Variations of Blank Bolts.**—The variations in size of blank bolts shall not exceed that allowed under Table III below:

## TABLE III

| Nominal Diameter | Maximum Diameter | Minimum Diameter | Maximum Variation | Nominal Diameter | Maximum Diameter | Minimum Diameter | Maximum Variation |
|---|---|---|---|---|---|---|---|
| *Inch* | *Inch* | *Inch* | *Inch* | *Inches* | *Inches* | *Inches* | *Inch* |
| 3/16 | 0.1925 | 0.1825 | 0.010 | 15/16 | .9465 | .9285 | 0.018 |
| 1/4 | .2550 | .245 | .010 | 1 | 1.0095 | .9905 | .019 |
| 5/16 | .3180 | .307 | .011 | 1⅛ | 1.1350 | 1.115 | .020 |
| 3/8 | .3810 | .369 | .012 | 1¼ | 1.2605 | 1.2395 | .021 |
| 7/16 | .444 | .431 | .013 | 1⅜ | 1.3855 | 1.3645 | .021 |
| 1/2 | .507 | .493 | .014 | 1½ | 1.5105 | 1.4895 | .021 |
| 9/16 | .570 | .555 | .015 | 1⅝ | 1.6355 | 1.6145 | .021 |
| 5/8 | .633 | .617 | .016 | 1¾ | 1.7605 | 1.7395 | .021 |
| 11/16 | .6955 | .6795 | .016 | 1⅞ | 1.886 | 1.864 | .022 |
| 3/4 | .7585 | .7415 | .017 | 2 | 2.011 | 1.989 | .022 |
| 13/16 | .821 | .804 | .017 | 2¼ | 2.261 | 2.239 | .022 |
| 7/8 | .8840 | .866 | .018 | 2½ | 2.511 | 2.489 | .022 |

## NUTS

13. **Manufactured Nuts.**—The nuts for use with steel bolts may be either steel or iron as specified, and shall conform to the following:

14. **Workmanship.**—Nuts shall be either hot pressed or cold punched from a solid bar. They must be free from scales, fins, seams, or other injurious or unsightly defects and must have cleanly and smoothly threaded holes of nominal size, square to the end faces of the nuts. All cold-punched nuts, whether blank or tapped, must be reamed square to their end faces before tapping; this reaming process may be omitted in hot-pressed nuts.

15. **Dimensions.**—Nuts shall conform to the dimensions given in Table I above and shall have United States standard threads, unless blanks are specifically called for. They shall be square or hexagonal, either plain or chamfered, or double chamfered, or faced on their lower sides, or counter-bored (recessed), as specified in the requisition. The chamfering to be as specified in paragraph 7.

16. **Tests.**—From each lot of steel or iron nuts having the same size and ready for final inspection there will be selected not less than two specimens or one for every 200 pounds or fraction thereof. One-half of the number selected shall be drifted cold until they break, the fracture to indicate either homogeneous steel or wrought iron. If fracture indicates wrought iron, the fibers must run at right angles to the axis of the hole. The remaining specimens shall be heated to redness and flattened to one-sixth of their thickness. Under this test, flaws or splits, due to defective steel or badly welded wrought iron, must not develop.

17. **Composition Nuts.**—To be made of the same material as required for composition rods under paragraph 4 and to conform as far as applicable to the requirements for steel nuts, including surface, threads, and fit.

## STUDS

18. **General.**—The length of threads on studs, including taper, shall be $1\frac{1}{2}$ times the diameter of the stud. The length of the taper shall not exceed two threads. The thread on one end of the stud shall be a steam-tight fit and the end of the stud shall be faced square with the axis; the thread on the other end of the stud shall be a thumb-tight nut fit and the end shall be rounded to a radius approximately equal to the diameter of the bolt. When specified for use on machinery, the nut on the stud shall be a wrench fit.

19. **Split Pin.**—When a split pin is required, the diameter and the material of the pin will be specified.

## MISCELLANEOUS REQUIREMENTS

20. **Fit.**—When bolts and nuts are ordered together, one nut shall be delivered on each bolt, which must fit the bolt as specified in the requisition (see paragraph 22). Bolts ordered separately must fit a nut of standard, nominal size, as specified in the requisition. Nuts ordered separately must be of standard, nominal size.

21. **Packing.**—Unless otherwise specified, all bolts and nuts must be packed in 100-pound boxes, made of new, sound boards of $\frac{7}{8}$-inch thickness, well nailed together and strapped at both ends with $\frac{1}{2}$-inch flat band iron. The boxes must have mill-dressed outside surfaces. Each box must be clearly stenciled on one end only, showing the net weight, the size, and name of the contents. The manufacturer's name, contract number, and any other marks may appear on one side only. One side, one end, the top, and bottom of the box shall be left free from marks.

22. **Instructions to General Storekeepers.**—The requisition for bolts and nuts should specify:

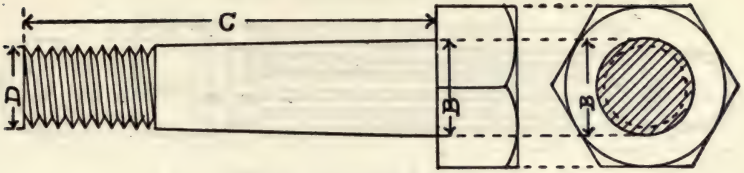
(a) The kind and class of material required.

(b) The form of the head, whether square, hexagonal, round, plain, chamfered, etc.

(c) Whether or not the nut, when semi-finished or machined, is to be counter-bored (recessed). This expression should be used in lieu of the word "cupped."

(d) Whether the bolts are to be threaded or blank.

STANDARD TAPER BOLTS

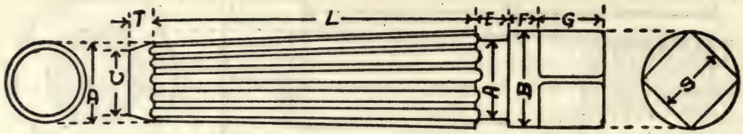



American Locomotive Practice

| For New Work | | | For Repair Work | | |
|---|---|---|---|---|---|
| Bolt No. | Length C | Diam. Under Head B | Bolt No. | Length C | Diam. Under Head B |
| 4 | 4 in. and less....... | D + $\frac{1}{32}$ in. | 4½ | 4 in. and less....... | D + $\frac{3}{64}$ in. |
| 8 | 8 in. to 4 in. not including 4 in...... | D + $\frac{1}{16}$ in. | 8½ | 8 in. to 4 in. not including 4 in...... | D + $\frac{5}{64}$ in. |
| 12 | 12 in. to 8 in. not including 8 in...... | D + $\frac{3}{32}$ in. | 12½ | 12 in. to 8 in. not including 8 in...... | D + $\frac{7}{64}$ in. |
| 16 | 16 in. to 12 in. not including 12 in..... | D + $\frac{1}{8}$ in. | 16½ | 16 in. to 12 in. not including 12 in..... | D + $\frac{9}{64}$ in. |
| 20 | 20 in. to 16 in. not including 16 in..... | D + $\frac{5}{32}$ in. | 20½ | 20 in. to 16 in. not including 16 in..... | D + $\frac{11}{64}$ in. |

This table relating to standard taper bolts for locomotives is an adaptation of dimensions given on drawings in the Locomotive Dictionary. The dimensions in table of reamers, given below, apply to the above table of taper bolts. As a standard this table has its limitations, inasmuch as other tapers are in use, notably the bolts in main and side rods for certain locomotives, Lehigh Valley design, the taper = $\frac{1}{16}$ in. in 12 inches; for similar rods $\frac{1}{8}$ in. in 12 inches is employed by the American Locomotive Co., and other variations could be given.

## Standard Taper Reamers




American Locomotive Practice

| D | L | A | B | C | E | F | G | S | T | Mark Reamer |
|---|---|---|---|---|---|---|---|---|---|---|
| $\frac{1}{2}$ | 8 | $\frac{1}{2}$ | $\frac{3}{4}$ | $\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{3}{4}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{1}{2}$ No. 4 |
| $\frac{1}{2}$ | 12 | $\frac{1}{2}$ | $\frac{3}{4}$ | $\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{3}{4}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{1}{2}$ " 8 |
| $\frac{5}{8}$ | 8 | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{9}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{3}{4}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{5}{8}$ " 4 |
| $\frac{5}{8}$ | 12 | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{9}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{3}{4}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{5}{8}$ " 8 |
| $\frac{3}{4}$ | 8 | $\frac{3}{4}$ | $1\frac{1}{16}$ | $\frac{11}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | 1 | $\frac{3}{4}$ | $\frac{1}{2}$ | $\frac{3}{4}$ " 4 |
| $\frac{3}{4}$ | 12 | $\frac{3}{4}$ | $1\frac{1}{16}$ | $\frac{11}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | 1 | $\frac{3}{4}$ | $\frac{1}{2}$ | $\frac{3}{4}$ " 8 |
| $\frac{3}{4}$ | 16 | $\frac{3}{4}$ | $1\frac{1}{16}$ | $\frac{11}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | 1 | $\frac{3}{4}$ | $\frac{1}{2}$ | $\frac{3}{4}$ " 12 |
| $\frac{3}{4}$ | 20 | $\frac{3}{4}$ | $1\frac{1}{16}$ | $\frac{11}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | 1 | $\frac{3}{4}$ | $\frac{1}{2}$ | $\frac{3}{4}$ " 16 |
| $\frac{7}{8}$ | 8 | $\frac{7}{8}$ | $1\frac{1}{4}$ | $\frac{13}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | $\frac{7}{8}$ | $\frac{1}{2}$ | $\frac{7}{8}$ " 4 |
| $\frac{7}{8}$ | 12 | $\frac{7}{8}$ | $1\frac{1}{4}$ | $\frac{13}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | $\frac{7}{8}$ | $\frac{1}{2}$ | $\frac{7}{8}$ " 8 |
| $\frac{7}{8}$ | 16 | $\frac{7}{8}$ | $1\frac{1}{4}$ | $\frac{13}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | $\frac{7}{8}$ | $\frac{1}{2}$ | $\frac{7}{8}$ " 12 |
| $\frac{7}{8}$ | 20 | $\frac{7}{8}$ | $1\frac{1}{4}$ | $\frac{13}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | $\frac{7}{8}$ | $\frac{1}{2}$ | $\frac{7}{8}$ " 16 |
| 1 | 8 | 1 | $1\frac{1}{4}$ | $\frac{15}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | $\frac{7}{8}$ | $\frac{1}{2}$ | 1 " 4 |
| 1 | 12 | 1 | $1\frac{1}{4}$ | $\frac{15}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | $\frac{7}{8}$ | $\frac{1}{2}$ | 1 " 8 |
| 1 | 16 | 1 | $1\frac{1}{4}$ | $\frac{15}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | $\frac{7}{8}$ | $\frac{1}{2}$ | 1 " 12 |
| 1 | 20 | 1 | $1\frac{1}{4}$ | $\frac{15}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | $\frac{7}{8}$ | $\frac{1}{2}$ | 1 " 16 |
| $1\frac{1}{8}$ | 8 | $1\frac{1}{8}$ | $1\frac{1}{2}$ | $1\frac{1}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | 1 | $\frac{1}{2}$ | $1\frac{1}{8}$ " 4 |
| $1\frac{1}{8}$ | 12 | $1\frac{1}{8}$ | $1\frac{1}{2}$ | $1\frac{1}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | 1 | $\frac{1}{2}$ | $1\frac{1}{8}$ " 8 |
| $1\frac{1}{8}$ | 16 | $1\frac{1}{8}$ | $1\frac{1}{2}$ | $1\frac{1}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | 1 | $\frac{1}{2}$ | $1\frac{1}{8}$ " 12 |
| $1\frac{1}{8}$ | 20 | $1\frac{1}{8}$ | $1\frac{1}{2}$ | $1\frac{1}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | 1 | $\frac{1}{2}$ | $1\frac{1}{8}$ " 16 |
| $1\frac{1}{4}$ | 8 | $1\frac{1}{4}$ | $1\frac{1}{2}$ | $1\frac{3}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | 1 | $\frac{1}{2}$ | $1\frac{1}{4}$ " 4 |
| $1\frac{1}{4}$ | 12 | $1\frac{1}{4}$ | $1\frac{1}{2}$ | $1\frac{3}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | 1 | $\frac{1}{2}$ | $1\frac{1}{4}$ " 8 |
| $1\frac{1}{4}$ | 16 | $1\frac{1}{4}$ | $1\frac{1}{2}$ | $1\frac{3}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | 1 | $\frac{1}{2}$ | $1\frac{1}{4}$ " 12 |
| $1\frac{1}{4}$ | 20 | $1\frac{1}{4}$ | $1\frac{1}{2}$ | $1\frac{3}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | 1 | $\frac{1}{2}$ | $1\frac{1}{4}$ " 16 |
| $1\frac{3}{8}$ | 8 | $1\frac{3}{8}$ | $1\frac{1}{2}$ | $1\frac{5}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | 1 | $\frac{1}{2}$ | $1\frac{3}{8}$ " 4 |
| $1\frac{3}{8}$ | 12 | $1\frac{3}{8}$ | $1\frac{1}{2}$ | $1\frac{5}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | 1 | $\frac{1}{2}$ | $1\frac{3}{8}$ " 8 |
| $1\frac{3}{8}$ | 16 | $1\frac{3}{8}$ | $1\frac{1}{2}$ | $1\frac{5}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | 1 | $\frac{1}{2}$ | $1\frac{3}{8}$ " 12 |
| $1\frac{3}{8}$ | 20 | $1\frac{3}{8}$ | $1\frac{1}{2}$ | $1\frac{5}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | 1 | $\frac{1}{2}$ | $1\frac{3}{8}$ " 16 |
| $1\frac{1}{2}$ | 8 | $1\frac{1}{2}$ | $1\frac{1}{2}$ | $1\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | 1 | $\frac{1}{2}$ | $1\frac{1}{2}$ " 4 |
| $1\frac{1}{2}$ | 12 | $1\frac{1}{2}$ | $1\frac{1}{2}$ | $1\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | 1 | $\frac{1}{2}$ | $1\frac{1}{2}$ " 8 |
| $1\frac{1}{2}$ | 16 | $1\frac{1}{2}$ | $1\frac{1}{2}$ | $1\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | 1 | $\frac{1}{2}$ | $1\frac{1}{2}$ " 12 |
| $1\frac{1}{2}$ | 20 | $1\frac{1}{2}$ | $1\frac{1}{2}$ | $1\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | 1 | $\frac{1}{2}$ | $1\frac{1}{2}$ " 16 |

NOTE.—1 inch reamers taper $\frac{3}{32}$ in. per foot.

To allow for grinding, each reamer is made 4 in. longer than longest bolt of its class. When a No. 12 reamer has been reduced $\frac{1}{32}$ in. in diameter and goes in up to the top of flutes when reaming for longest bolt of its class, by cutting 4 in. from the small end it can be used as a No. 8 reamer, and afterwards as a No. 4.

## Machine Bolts with Square Heads and Square Nuts

Manufacturer's Standard

Average weight per hundred

| Lgth. in Ins. | Diameters | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ½ | 9/16 | ⅝ | ¾ | ⅞ | 1 | 1⅛ | 1¼ |
| 3 | 26 | 38 | 45 | 72 | 106 | 157 | 211 | 286 |
| 3½ | 29 | 42 | 49 | 78 | 115 | 167 | 226 | 303 |
| 4 | 31 | 46 | 53 | 83 | 123 | 176 | 240 | 320 |
| 4½ | 34 | 50 | 57 | 89 | 131 | 18[illegible] | 255 | 337 |
| 5 | 37 | 54 | 60 | 95 | 139 | 196 | 269 | 354 |
| 5½ | 39 | 58 | 64 | 101 | 148 | 206 | 284 | 371 |
| 6 | 42 | 61 | 68 | 106 | 156 | 216 | 298 | 388 |
| 6½ | 45 | 65 | 72 | 112 | 164 | 225 | 313 | 405 |
| 7 | 47 | 69 | 75 | 118 | 172 | 235 | 327 | 422 |
| 7½ | 50 | 73 | 79 | 124 | 181 | 245 | 342 | 439 |
| 8 | 53 | 77 | 83 | 129 | 189 | 255 | 356 | 456 |
| 9 | 58 | 84 | 90 | 141 | 205 | 274 | 385 | 490 |
| 10 | 63 | 92 | 98 | 152 | 222 | 294 | 414 | 524 |
| 11 | 69 | 100 | 105 | 164 | 238 | 314 | 443 | 558 |
| 12 | 74 | 107 | 113 | 175 | 255 | 333 | 472 | 592 |
| 13 | 79 | 115 | 120 | 187 | 271 | 352 | 501 | 626 |
| 14 | 84 | 122 | 128 | 198 | 288 | 372 | 530 | 660 |
| 15 | 89 | 129 | 135 | 210 | 304 | 391 | 559 | 694 |
| 16 | 95 | 137 | 143 | 221 | 320 | 410 | 588 | 728 |
| 17 | 100 | 144 | 150 | 233 | 336 | 429 | 617 | 762 |
| 18 | 105 | 152 | 157 | 244 | 353 | 448 | 646 | 796 |
| 19 | 110 | 159 | 165 | 256 | 369 | 468 | 675 | 830 |
| 20 | 115 | 166 | 172 | 267 | 385 | 487 | 704 | 864 |

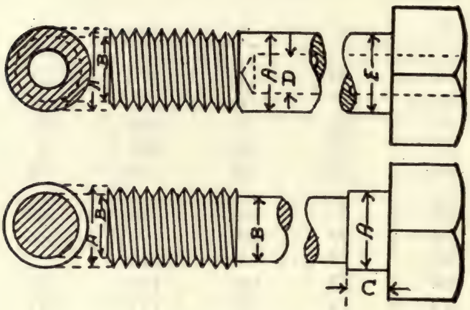
## Bolts of Uniform Strength

The effective area of a bolt is that corresponding to its diameter at the bottom of thread. A bolt that is subject to repeated shock or stress suffers a slight temporary elongation every time the shock occurs. In a solid bolt the smallest area which is under stress is at the base of the threads between the nut and the body of the bolt and the slight elongation due to each shock is largely localized at this point, causing the metal to crystallize and give way. By reducing the area of the body of the bolt until it is equal to or less than the area at the base of the threads the elongation distributes itself more uniformly through the entire length of the bolt, and thus the strain on each particle of metal is less than when it is all located between the nut and the body of the bolt.

The area of the bolt can be reduced either by drilling out the center or by turning off the outside, but as the latter method weakens the bolt more torsionally the drilling is preferable. C. L. Thompson.

When computing the table on page 392, the nearest $\frac{1}{32}$-inch drill was selected; in ordinary shop practice a drilled hole is slightly larger than the drill used to make it, the net area of a hollow bolt at E (see sketch) may, therefore, be slightly less than given.

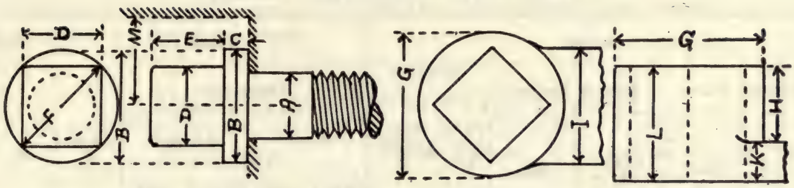
## Bolts of Uniform Strength




United States Standard Threads

| Screw | | | | Length of Neck C | Hole | | | Weight per Inch | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Outside | | Root of Thread | | | Diam. D | Area | Net Area of Bolt at E | Solid A | Solid B | Hollow Section E |
| Dia. A | Area | Diam. B | Area | | | | | | | |
| 1 | .785 | .837 | .550 | $\frac{1}{2}$ | $\frac{17}{32}$ | .222 | .563 | .222 | .156 | .160 |
| $1\frac{1}{8}$ | .994 | .940 | .694 | $\frac{1}{2}$ | $\frac{5}{8}$ | .307 | .687 | .282 | .197 | .195 |
| $1\frac{1}{4}$ | 1.227 | 1.065 | .891 | $\frac{9}{16}$ | $\frac{21}{32}$ | .338 | .889 | .348 | .252 | .252 |
| $1\frac{3}{8}$ | 1.485 | 1.160 | 1.057 | $\frac{9}{16}$ | $\frac{3}{4}$ | .442 | 1.043 | .421 | .299 | .296 |
| $1\frac{1}{2}$ | 1.767 | 1.284 | 1.294 | $\frac{9}{16}$ | $\frac{25}{32}$ | .479 | 1.288 | .501 | .367 | .365 |
| $1\frac{5}{8}$ | 2.074 | 1.389 | 1.515 | $\frac{5}{8}$ | $\frac{27}{32}$ | .559 | 1.515 | .588 | .429 | .429 |
| $1\frac{3}{4}$ | 2.405 | 1.491 | 1.746 | $\frac{5}{8}$ | $\frac{29}{32}$ | .645 | 1.760 | .681 | .495 | .499 |
| $1\frac{7}{8}$ | 2.761 | 1.616 | 2.051 | $\frac{5}{8}$ | $\frac{15}{16}$ | .690 | 2.071 | .782 | .581 | .587 |
| 2 | 3.142 | 1.712 | 2.302 | $\frac{5}{8}$ | 1 | .785 | 2.357 | .890 | .652 | .668 |
| $2\frac{1}{4}$ | 3.976 | 1.962 | 3.023 | $\frac{3}{4}$ | $1\frac{1}{8}$ | .994 | 2.982 | 1.127 | .857 | .845 |
| $2\frac{1}{2}$ | 4.909 | 2.176 | 3.719 | $\frac{3}{4}$ | $1\frac{3}{16}$ | 1.108 | 3.801 | 1.391 | 1.054 | 1.077 |
| $2\frac{3}{4}$ | 5.940 | 2.426 | 4.622 | $\frac{3}{4}$ | $1\frac{5}{16}$ | 1.353 | 4.587 | 1.683 | 1.310 | 1.300 |
| 3 | 7.069 | 2.676 | 5.624 | $\frac{3}{4}$ | $1\frac{7}{16}$ | 1.623 | 5.446 | 2.000 | 1.594 | 1.543 |
| $3\frac{1}{4}$ | 8.296 | 2.879 | 6.509 | $\frac{7}{8}$ | $1\frac{1}{2}$ | 1.767 | 6.529 | 2.351 | 1.844 | 1.850 |
| $3\frac{1}{2}$ | 9.621 | 3.100 | 7.549 | $\frac{7}{8}$ | $1\frac{5}{8}$ | 2.074 | 7.547 | 2.726 | 2.139 | 2.138 |
| $3\frac{3}{4}$ | 11.05 | 3.317 | 8.641 | $\frac{7}{8}$ | $1\frac{3}{4}$ | 2.405 | 8.64 | 3.131 | 2.448 | 2.448 |
| 4 | 12.57 | 3.567 | 9.993 | 1 | $1\frac{13}{16}$ | 2.580 | 9.99 | 3.562 | 2.831 | 2.831 |

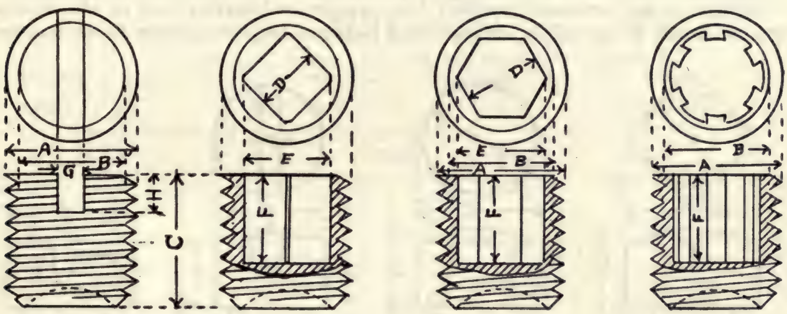
### Collar Screws with Square Heads




| Screw | | | | | | Wrench | | | | | Counter bore |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Diam A | B | C | Square D | E | F | G | H | I | K | L | M |
| $\frac{1}{2}$ | $\frac{7}{8}$ | $\frac{1}{4}$ | $\frac{5}{8}$ | $\frac{1}{2}$ | $\frac{7}{8}$ | $1\frac{1}{8}$ | $\frac{5}{8}$ | $\frac{7}{8}$ | $\frac{1}{4}$ | $\frac{15}{16}$ | $\frac{11}{16}$ |
| $\frac{5}{8}$ | $1\frac{1}{16}$ | $\frac{5}{16}$ | $\frac{3}{4}$ | $\frac{9}{16}$ | $1\frac{1}{16}$ | $1\frac{5}{16}$ | $\frac{11}{16}$ | 1 | $\frac{5}{16}$ | 1 | $\frac{13}{16}$ |
| $\frac{4}{4}$ | $1\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{13}{16}$ | $\frac{5}{8}$ | $1\frac{1}{8}$ | $1\frac{9}{16}$ | $\frac{3}{4}$ | $1\frac{1}{8}$ | $\frac{3}{8}$ | $1\frac{1}{8}$ | $\frac{7}{8}$ |
| $\frac{7}{8}$ | $1\frac{7}{16}$ | $\frac{3}{8}$ | $\frac{15}{16}$ | $\frac{11}{16}$ | $1\frac{5}{16}$ | $1\frac{3}{4}$ | $\frac{3}{4}$ | $1\frac{1}{4}$ | $\frac{3}{8}$ | $1\frac{1}{8}$ | 1 |
| 1 | $1\frac{5}{8}$ | $\frac{3}{8}$ | $1\frac{1}{16}$ | $\frac{3}{4}$ | $1\frac{1}{2}$ | $1\frac{15}{16}$ | $\frac{13}{16}$ | $1\frac{3}{8}$ | $\frac{7}{16}$ | $1\frac{1}{4}$ | $1\frac{1}{8}$ |
| $1\frac{1}{8}$ | $1\frac{13}{16}$ | $\frac{7}{16}$ | $1\frac{3}{16}$ | $\frac{13}{16}$ | $1\frac{11}{16}$ | $2\frac{1}{8}$ | $\frac{7}{8}$ | $1\frac{7}{16}$ | $\frac{1}{2}$ | $1\frac{3}{8}$ | $1\frac{1}{4}$ |
| $1\frac{1}{4}$ | 2 | $\frac{7}{16}$ | $1\frac{5}{16}$ | $\frac{7}{8}$ | $1\frac{7}{8}$ | $2\frac{3}{8}$ | $\frac{15}{16}$ | $1\frac{9}{16}$ | $\frac{1}{2}$ | $1\frac{7}{16}$ | $1\frac{5}{16}$ |
| $1\frac{3}{8}$ | $2\frac{3}{16}$ | $\frac{1}{2}$ | $1\frac{7}{16}$ | $\frac{15}{16}$ | 2 | $2\frac{9}{16}$ | 1 | $1\frac{5}{8}$ | $\frac{9}{16}$ | $1\frac{9}{16}$ | $1\frac{7}{16}$ |
| $1\frac{1}{2}$ | $2\frac{3}{8}$ | $\frac{1}{2}$ | $1\frac{1}{2}$ | 1 | $2\frac{1}{8}$ | $2\frac{3}{4}$ | 1 | $1\frac{3}{4}$ | $\frac{5}{8}$ | $1\frac{5}{8}$ | $1\frac{1}{2}$ |

### Headless Set Screws

A set screw with projecting head, such as sometimes seen in a collar or hub of a wheel fixed upon a revolving shaft, is always to be regarded as a hazard because of the constant liability of the projecting head engaging the clothing of an attendant; to eliminate this hazard is the purpose of the headless and non-projecting set screw.




NOTE.—By slightly rounding the corners in a square socket a shortening of its long diameter is had without materially affecting the action of the wrench, provided the latter snugly fits the socket. Wrenches for hollow set screws are usually furnished by the manufacturers of the screws.

## Headless Set Screws

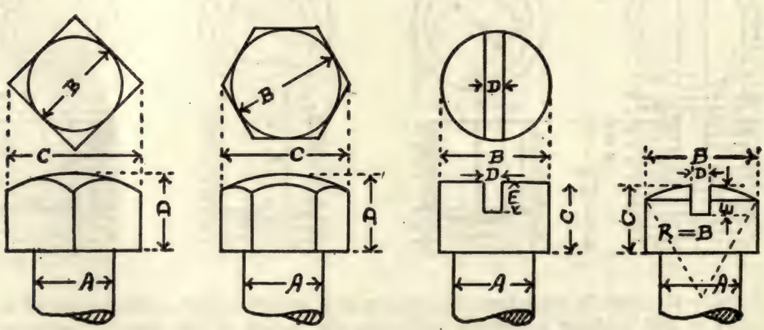
### United States Standard Threads

| Screw | | | | | | Hole | | | | | Slot | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Outside Diam. | | Root of Thread | | Thds. per In. | Min. Length C | Diameters | | | | Depth F | G | H |
| | | | | | | Square | | Hexagon | | | | |
| A | Area | Diam. B | Area | | | Short D | Long E | Short D | Long E | | | |
| 1/4 | .049 | .185 | .027 | 20 | 5/16 | 7/64 | 5/32 | 7/64 | 1/8 | 7/64 | 1/16 | 1/8 |
| 5/16 | .077 | .240 | .045 | 18 | 5/16 | 5/32 | 7/32 | 5/32 | 3/16 | 5/32 | 5/64 | 9/64 |
| 3/8 | .111 | .294 | .068 | 16 | 3/8 | 3/16 | 17/64 | 3/16 | 7/32 | 3/16 | 5/64 | 9/64 |
| 7/16 | .150 | .335 | .093 | 14 | 7/16 | 7/32 | 19/64 | 1/4 | 19/64 | 1/4 | 3/32 | 5/32 |
| 1/2 | .196 | .400 | .126 | 13 | 1/2 | 1/4 | 23/64 | 5/16 | 23/64 | 5/16 | 3/32 | 11/64 |
| 9/16 | .249 | .454 | .162 | 12 | 9/16 | 9/32 | 13/32 | 11/32 | 13/32 | 7/16 | 7/64 | 3/16 |
| 5/8 | .307 | .507 | .202 | 11 | 5/8 | 5/16 | 7/16 | 3/8 | 7/16 | 1/2 | 1/8 | 3/16 |
| 3/4 | .442 | .620 | .302 | 10 | 3/4 | 3/8 | 17/32 | 29/64 | 17/32 | 9/16 | 9/64 | 7/32 |
| 7/8 | .601 | .731 | .419 | 9 | 7/8 | 7/16 | 39/64 | 33/64 | 19/32 | 5/8 | 5/32 | 1/4 |
| 1 | .785 | .838 | .550 | 8 | 1 | 1/2 | 45/64 | 19/32 | 11/16 | 11/16 | 11/64 | 17/64 |
| 1 1/8 | .994 | .939 | .694 | 7 | 1 1/8 | 9/16 | 51/64 | 43/64 | 49/64 | 3/4 | 13/64 | 9/32 |
| 1 1/4 | 1.227 | 1.065 | .891 | 7 | 1 1/4 | 5/8 | 57/64 | 3/4 | 55/64 | 13/16 | 7/32 | 5/16 |
| 1 3/8 | 1.485 | 1.159 | 1.057 | 6 | 1 3/8 | 11/16 | 31/32 | 13/16 | 15/16 | 7/8 | 7/32 | 5/16 |
| 1 1/2 | 1.767 | 1.284 | 1.294 | 6 | 1 1/2 | 3/4 | 1 1/16 | 29/32 | 1 3/64 | 1 | 1/4 | 3/8 |

## CAP SCREWS

Threads, in general, follow the United States Standard; in the case of half-inch screws, however, there seems to be a preference for 12 threads, rather than 13, the standard number.

Cap screws are, ordinarily, milled from square or hexagon bars of the dimensions given for heads in the table. Square and hexagon heads requiring to be finished are




ground and polished from the rough; they are not milled to size, hence, the dimensions given are approximate only.

Length of thread is ordinarily cut three-fourths of the length under the head for cap screws 1 inch and less in diameter, when not over 4 inches in length; when longer than 4 inches, the threads are commonly half the length.

## CAP SCREWS

Round head cap screws are milled to dimensions given in the table; the heads are therefore true to size and accurately centered.

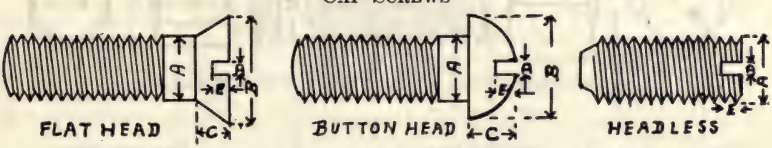
Flat and button head cap screws are milled from bars slightly larger than the diameter of head; they are not upset heads.

### Cap Screws

Commercial sizes. Not United States Standard

| Screw | | Square Head | | | Hexagon Head | | | Round and Filister Head | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Diam. A | Thds. per Inch | Short Diam. B | Long Diam. C | Height D | Short Diam. B | Long Diam. C | Height D | Diam. B | Height C | Slot Width D | Slot Depth E |
| 1/4 | 20 | 3/8 | 17/32 | 1/4 | 7/16 | 1/2 | 1/4 | 3/8 | 1/4 | 1/16 | 1/8 |
| 5/16 | 18 | 7/16 | 5/8 | 5/16 | 1/2 | 37/64 | 5/16 | 7/16 | 5/16 | 5/64 | 9/64 |
| 3/8 | 16 | 1/2 | 45/64 | 3/8 | 9/16 | 21/32 | 3/8 | 9/16 | 3/8 | 5/64 | 5/32 |
| 7/16 | 14 | 9/16 | 51/64 | 7/16 | 5/8 | 23/32 | 7/16 | 5/8 | 7/16 | 3/32 | 5/32 |
| 1/2 | 12 | 5/8 | 57/64 | 1/2 | 3/4 | 7/8 | 1/2 | 3/4 | 1/2 | 3/32 | 11/64 |
| 9/16 | 12 | 11/16 | 31/32 | 9/16 | 13/16 | 15/16 | 9/16 | 13/16 | 9/16 | 7/64 | 3/16 |
| 5/8 | 11 | 3/4 | 1 1/16 | 5/8 | 7/8 | 1 1/64 | 5/8 | 7/8 | 5/8 | 1/8 | 3/16 |
| 3/4 | 10 | 7/8 | 1 15/64 | 3/4 | 1 | 1 5/32 | 3/4 | 1 | 3/4 | 9/64 | 7/32 |
| 7/8 | 9 | 1 1/8 | 1 19/32 | 7/8 | 1 1/8 | 1 19/64 | 7/8 | 1 1/8 | 7/8 | 5/32 | 1/4 |
| 1 | 8 | 1 1/4 | | 1 | 1 1/4 | 1 7/16 | 1 | 1 1/4 | 1 | 11/64 | 17/64 |
| 1 1/8 | 7 | 1 3/8 | 1 49/64 | 1 1/8 | 1 3/8 | 1 19/32 | 1 1/8 | 1 3/8 | 1 1/8 | 13/64 | 9/32 |
| 1 1/4 | 7 | 1 1/2 | 2 1/8 | 1 1/4 | 1 1/2 | 1 47/64 | 1 1/4 | 1 1/2 | 1 1/4 | 7/32 | 5/16 |

### Cap Screws




Commercial Sizes. Not United States Standard

| Screw | | Flat Head | | | | Button Head | | | |
|---|---|---|---|---|---|---|---|---|---|
| Diam. A | Threads per Inch | Diam. B | Height C | Slot Width D | Slot Depth E | Diam. B | Height C | Slot Width D | Slot Depth E |
| 1/8 | 40 | 1/4 | 1/16 | 1/32 | 1/32 | 15/64 | 7/64 | 1/32 | 1/32 |
| 3/16 | 24 | 3/8 | 3/32 | 3/64 | 1/16 | 5/16 | 5/32 | 3/64 | 3/64 |
| 1/4 | 20 | 15/32 | 1/8 | 1/16 | 1/8 | 7/16 | 13/64 | 1/16 | 5/64 |
| 5/16 | 18 | 5/8 | 5/32 | 5/64 | 9/64 | 9/16 | 1/4 | 5/64 | 7/64 |
| 3/8 | 16 | 3/4 | 3/16 | 5/64 | 5/32 | 5/8 | 19/64 | 5/64 | 7/64 |
| 7/16 | 14 | 13/16 | 7/32 | 3/32 | 5/32 | 3/4 | 23/64 | 3/32 | 9/64 |
| 1/2 | 12 | 7/8 | 1/4 | 3/32 | 11/64 | 13/16 | 13/32 | 3/32 | 5/32 |
| 9/16 | 12 | 1 | 9/32 | 7/64 | 3/16 | 15/16 | 29/64 | 7/64 | 3/16 |
| 5/8 | 11 | 1 1/8 | 5/16 | 1/8 | 3/16 | 1 | 1/2 | 1/8 | 13/64 |
| 3/4 | 10 | 1 3/8 | 3/8 | 9/64 | 7/32 | 1 1/4 | 39/64 | 9/64 | 1/4 |

# SET SCREWS

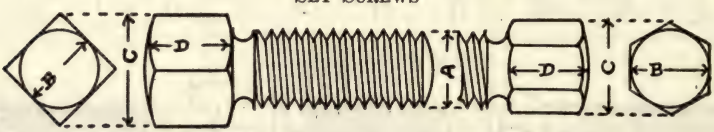
Commercial set screws do not have upset or forged heads. The diameter of screw, the short diameter of head, and the height of head are the same or nearly so. When


the short diameter of head exceeds that of the screw diameter by more than $\frac{1}{16}$ inch, it is not then classed as a set screw but as a cap screw.

Points of set screws vary in shape, depending upon the uses to which the screws are to be put; the leading varieties of points are shown in the accompanying sketches. Cup and oval point set screws are regular; others are special and made to order.

Heads are commonly square; should hexagon heads be required they will be made to order at about 25 per cent advance over the square head net prices.

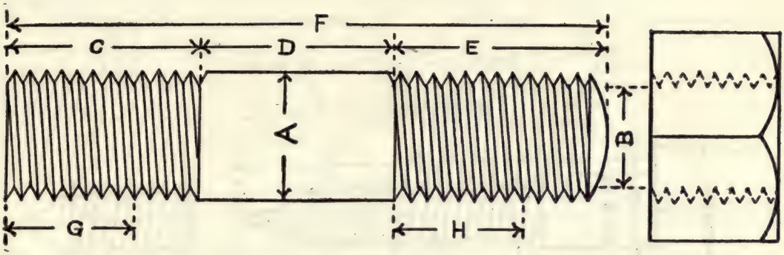
Set Screws




Commercial Sizes. Not United States Standard

| Screw | | Square Head | | | Hexagon Head | | |
|---|---|---|---|---|---|---|---|
| Diam. A | Threads per Inch | Short Diam. B | Long Diam. C | Height D | Short Diam. B | Long Diam. C | Height D |
| $\frac{1}{4}$ | 20 | $\frac{1}{4}$ | $\frac{23}{64}$ | $\frac{1}{4}$ | $\frac{1}{4}$ | $\frac{19}{64}$ | $\frac{1}{4}$ |
| $\frac{5}{16}$ | 18 | $\frac{5}{16}$ | $\frac{29}{64}$ | $\frac{5}{16}$ | $\frac{5}{16}$ | $\frac{23}{64}$ | $\frac{5}{16}$ |
| $\frac{3}{8}$ | 16 | $\frac{3}{8}$ | $\frac{17}{32}$ | $\frac{3}{8}$ | $\frac{3}{8}$ | $\frac{7}{16}$ | $\frac{3}{8}$ |
| $\frac{7}{16}$ | 14 | $\frac{7}{16}$ | $\frac{5}{8}$ | $\frac{7}{16}$ | $\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{7}{16}$ |
| $\frac{1}{2}$ | 12 | $\frac{1}{2}$ | $\frac{45}{64}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{37}{64}$ | $\frac{1}{2}$ |
| $\frac{9}{16}$ | 12 | $\frac{9}{16}$ | $\frac{51}{64}$ | $\frac{9}{16}$ | $\frac{9}{16}$ | $\frac{21}{32}$ | $\frac{9}{16}$ |
| $\frac{5}{8}$ | 11 | $\frac{5}{8}$ | $\frac{57}{64}$ | $\frac{5}{8}$ | $\frac{5}{8}$ | $\frac{23}{32}$ | $\frac{5}{8}$ |
| $\frac{3}{4}$ | 10 | $\frac{3}{4}$ | $1\frac{1}{16}$ | $\frac{3}{4}$ | $\frac{3}{4}$ | $\frac{7}{8}$ | $\frac{3}{4}$ |
| $\frac{7}{8}$ | 9 | $\frac{7}{8}$ | $1\frac{1}{4}$ | $\frac{7}{8}$ | $\frac{7}{8}$ | $1\frac{1}{64}$ | $\frac{7}{8}$ |
| 1 | 8 | 1 | $1\frac{13}{32}$ | 1 | 1 | $1\frac{5}{32}$ | 1 |
| $1\frac{1}{8}$ | 7 | $1\frac{1}{8}$ | $1\frac{19}{32}$ | $1\frac{1}{8}$ | $1\frac{1}{8}$ | $1\frac{19}{64}$ | $1\frac{1}{8}$ |
| $1\frac{1}{4}$ | 7 | $1\frac{1}{4}$ | $1\frac{49}{32}$ | $1\frac{1}{4}$ | $1\frac{1}{4}$ | $1\frac{7}{16}$ | $1\frac{1}{4}$ |

## Studs

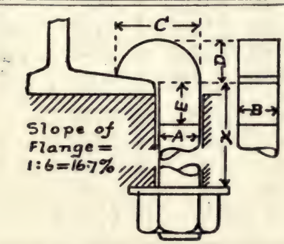



Commercial Sizes. United States Standard Thr ads

| Diameter A | Threads per Inch | Diameter at Root of Thread B | Areas: Outside Diameter A | Areas: Root of Thread B | Length of Tap End C | Blank D | Length of Nut End E | Length of Stud F |
|---|---|---|---|---|---|---|---|---|
| $\frac{1}{2}$ | 13 | .400 | .196 | .125 | $\frac{5}{8}$ | 0 | $\frac{3}{4}$ | $1\frac{3}{8}$ |
| $\frac{9}{16}$ | 12 | .454 | .249 | .162 | $\frac{11}{16}$ | 0 | $\frac{27}{32}$ | $1\frac{17}{32}$ |
| $\frac{5}{8}$ | 11 | .507 | .307 | .202 | $\frac{25}{32}$ | 0 | $\frac{15}{16}$ | $1\frac{23}{32}$ |
| $\frac{3}{4}$ | 10 | .620 | .442 | .302 | $\frac{15}{16}$ | 0 | $1\frac{1}{8}$ | $2\frac{1}{16}$ |
| $\frac{7}{8}$ | 9 | .731 | .601 | .419 | $1\frac{3}{32}$ | 0 | $1\frac{5}{16}$ | $2\frac{13}{32}$ |
| 1 | 8 | .837 | .785 | .550 | $1\frac{1}{4}$ | 0 | $1\frac{1}{2}$ | $2\frac{3}{4}$ |
| $1\frac{1}{8}$ | 7 | .940 | .994 | .694 | $1\frac{13}{32}$ | 0 | $1\frac{11}{16}$ | $3\frac{3}{32}$ |
| $1\frac{1}{4}$ | 7 | 1.065 | 1.227 | .892 | $1\frac{9}{16}$ | 0 | $1\frac{7}{8}$ | $3\frac{7}{16}$ |
| $1\frac{3}{8}$ | 6 | 1.160 | 1.485 | 1.057 | $1\frac{23}{32}$ | 0 | $2\frac{1}{16}$ | $3\frac{25}{32}$ |
| $1\frac{1}{2}$ | 6 | 1.284 | 1.767 | 1.294 | $1\frac{7}{8}$ | 0 | $2\frac{1}{4}$ | $4\frac{1}{8}$ |

The distance D in the table is zero, and F = C + O + E. As F is the working distance, whatever length is added to F is also to be added to D.

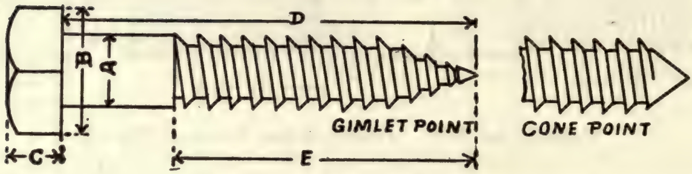
## Hook Bolts




| Diam. A | Square Neck: B | Square Neck: E | Head: C | Head: D |
|---|---|---|---|---|
| $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{3}{4}$ | 1 | $\frac{1}{2}$ |
| $\frac{5}{8}$ | $\frac{5}{8}$ | $\frac{7}{8}$ | $1\frac{1}{8}$ | $\frac{5}{8}$ |
| $\frac{3}{4}$ | $\frac{3}{4}$ | $\frac{7}{8}$ | $1\frac{3}{8}$ | $\frac{3}{4}$ |
| $\frac{7}{8}$ | $\frac{7}{8}$ | 1 | $1\frac{5}{8}$ | $\frac{7}{8}$ |
| 1 | 1 | 1 | $1\frac{3}{4}$ | 1 |

## Coach and Lag Screws

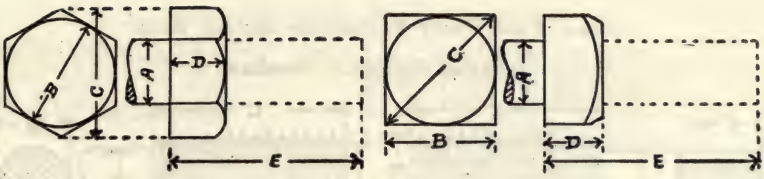
### Manufacturers' Standard




Average weight per 100 screws

| Diameter A | | $\frac{3}{8}$ | $\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{9}{16}$ | $\frac{5}{8}$ | $\frac{3}{4}$ | $\frac{7}{8}$ | 1 |
|---|---|---|---|---|---|---|---|---|---|
| Threads per Inch | | 8 | 7 | 6 | 6 | 5 | 5 | 4 | 4 |
| Length D | Length of Thread C | Head $\frac{9}{16}$ x $\frac{5}{16}$ | Head $\frac{11}{16}$ x $\frac{3}{8}$ | Head $\frac{3}{4}$ x $\frac{7}{16}$ | Head $\frac{7}{8}$ x $\frac{7}{16}$ | Head $\frac{15}{16}$ x $\frac{17}{32}$ | Head $1\frac{1}{8}$ x $\frac{5}{8}$ | Head $1\frac{5}{16}$ x $\frac{3}{4}$ | Head $1\frac{1}{2}$ x $\frac{7}{8}$ |
| 2 | $1\frac{1}{4}$ | 8 | 11 | 15 | 23 | 25 | ... | ... | ... |
| $2\frac{1}{2}$ | $1\frac{1}{2}$ | 9 | 13 | 18 | 26 | 29 | 43 | ... | ... |
| 3 | $1\frac{3}{4}$ | 11 | 15 | 19 | 29 | 33 | 48 | 75 | ... |
| $3\frac{1}{2}$ | 2 | 12 | 17 | 22 | 33 | 37 | 54 | 79 | 90 |
| 4 | $2\frac{1}{4}$ | 14 | 19 | 24 | 36 | 41 | 60 | 82 | 99 |
| $4\frac{1}{2}$ | $2\frac{1}{2}$ | 15 | 21 | 27 | 39 | 45 | 66 | 86 | 108 |
| 5 | $2\frac{3}{4}$ | 17 | 23 | 29 | 43 | 49 | 72 | 90 | 118 |
| $5\frac{1}{2}$ | 3 | 18 | 25 | 32 | 46 | 53 | 78 | 98 | 128 |
| 6 | $3\frac{1}{4}$ | 20 | 27 | 34 | 50 | 57 | 84 | 106 | 138 |
| 7 | $3\frac{3}{4}$ | .. | 31 | 39 | 56 | 65 | 96 | 123 | 158 |
| 8 | $4\frac{1}{4}$ | .. | 35 | 44 | 63 | 73 | 108 | 139 | 178 |
| 9 | $4\frac{3}{4}$ | .. | .. | 49 | 70 | 81 | 120 | 156 | 198 |
| 10 | 5 | .. | .. | 54 | 77 | 89 | 131 | 172 | 219 |
| 11 | 5 | .. | .. | .. | 84 | 97 | 143 | 189 | 240 |
| 12 | 5 | .. | .. | .. | 91 | 105 | 156 | 205 | 261 |

BOLT-HEADS

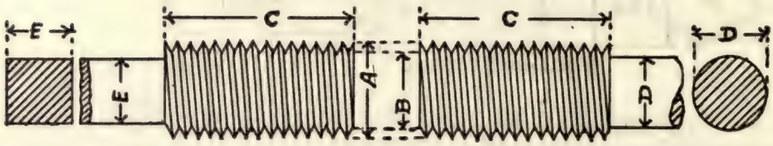



Length of Bar for Upset. United States Standard Heads

| Bar | | Hexagon Heads | | | | | Square Heads | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Diam. A | Area | Short Diam. B | Long Diam. C | Area Square Inches | Height of Head D | Length of Bar E | Short Diam. B | Long Diam. C | Area Square Inches | Height of Head D | Length of Bar E |
| $\frac{1}{4}$ | .049 | $\frac{1}{2}$ | $\frac{9}{16}$ | .217 | $\frac{1}{4}$ | $1\frac{3}{32}$ | $\frac{1}{2}$ | $\frac{23}{32}$ | .250 | $\frac{1}{4}$ | $1\frac{9}{32}$ |
| $\frac{5}{16}$ | .077 | $\frac{19}{32}$ | $\frac{11}{16}$ | .305 | $\frac{19}{64}$ | $1\frac{3}{16}$ | $\frac{19}{32}$ | $\frac{27}{32}$ | .353 | $\frac{19}{64}$ | $1\frac{3}{8}$ |
| $\frac{3}{8}$ | .110 | $\frac{11}{16}$ | $\frac{25}{32}$ | .409 | $\frac{11}{32}$ | $1\frac{9}{32}$ | $\frac{11}{16}$ | $\frac{31}{32}$ | .473 | $\frac{11}{32}$ | $1\frac{1}{2}$ |
| $\frac{7}{16}$ | .150 | $\frac{25}{32}$ | $\frac{29}{32}$ | .529 | $\frac{25}{64}$ | $1\frac{3}{8}$ | $\frac{25}{32}$ | $1\frac{3}{32}$ | .610 | $\frac{25}{64}$ | $1\frac{19}{32}$ |
| $\frac{1}{2}$ | .196 | $\frac{7}{8}$ | 1 | .663 | $\frac{7}{16}$ | $1\frac{1}{2}$ | $\frac{7}{8}$ | $1\frac{1}{4}$ | .766 | $\frac{7}{16}$ | $1\frac{23}{32}$ |
| $\frac{9}{16}$ | .249 | $\frac{31}{32}$ | $1\frac{1}{8}$ | .813 | $\frac{31}{64}$ | $1\frac{19}{32}$ | $\frac{31}{32}$ | $1\frac{3}{8}$ | .938 | $\frac{31}{64}$ | $1\frac{13}{16}$ |
| $\frac{5}{8}$ | .307 | $1\frac{1}{16}$ | $1\frac{7}{32}$ | .979 | $\frac{17}{32}$ | $1\frac{11}{16}$ | $1\frac{1}{16}$ | $1\frac{1}{2}$ | 1.129 | $\frac{17}{32}$ | $1\frac{31}{32}$ |
| $\frac{3}{4}$ | .442 | $1\frac{1}{4}$ | $1\frac{7}{16}$ | 1.353 | $\frac{5}{8}$ | $1\frac{29}{32}$ | $1\frac{1}{4}$ | $1\frac{3}{4}$ | 1.563 | $\frac{5}{8}$ | $2\frac{7}{32}$ |
| $\frac{7}{8}$ | .601 | $1\frac{7}{16}$ | $1\frac{21}{32}$ | 1.791 | $\frac{23}{32}$ | $2\frac{5}{32}$ | $1\frac{7}{16}$ | $2\frac{1}{32}$ | 2.066 | $\frac{23}{32}$ | $2\frac{15}{32}$ |
| 1 | .785 | $1\frac{5}{8}$ | $1\frac{7}{8}$ | 2.287 | $\frac{13}{16}$ | $2\frac{3}{8}$ | $1\frac{5}{8}$ | $2\frac{5}{16}$ | 2.641 | $\frac{13}{16}$ | $2\frac{3}{4}$ |
| $1\frac{1}{8}$ | .994 | $1\frac{13}{16}$ | $2\frac{3}{32}$ | 2.847 | $\frac{29}{32}$ | $2\frac{19}{32}$ | $1\frac{13}{16}$ | $2\frac{9}{16}$ | 3.285 | $\frac{29}{32}$ | 3 |
| $1\frac{1}{4}$ | 1.228 | 2 | $2\frac{5}{16}$ | 3.464 | 1 | $2\frac{13}{16}$ | 2 | $2\frac{27}{32}$ | 4.000 | 1 | $3\frac{1}{4}$ |
| $1\frac{3}{8}$ | 1.485 | $2\frac{3}{16}$ | $2\frac{17}{32}$ | 4.146 | $1\frac{3}{32}$ | $3\frac{1}{16}$ | $2\frac{3}{16}$ | $3\frac{3}{32}$ | 4.785 | $1\frac{3}{32}$ | $3\frac{19}{32}$ |
| $1\frac{1}{2}$ | 1.767 | $2\frac{3}{8}$ | $2\frac{3}{4}$ | 4.885 | $1\frac{3}{16}$ | $3\frac{9}{32}$ | $2\frac{3}{8}$ | $3\frac{11}{32}$ | 5.641 | $1\frac{3}{16}$ | $3\frac{13}{16}$ |
| $1\frac{5}{8}$ | 2.074 | $2\frac{9}{16}$ | $2\frac{31}{32}$ | 5.689 | $1\frac{9}{32}$ | $3\frac{1}{2}$ | $2\frac{9}{16}$ | $3\frac{5}{8}$ | 6.566 | $1\frac{9}{32}$ | $4\frac{1}{16}$ |
| $1\frac{3}{4}$ | 2.405 | $2\frac{3}{4}$ | $3\frac{3}{16}$ | 6.549 | $1\frac{3}{8}$ | $3\frac{3}{4}$ | $2\frac{3}{4}$ | $3\frac{7}{8}$ | 7.563 | $1\frac{3}{8}$ | $4\frac{5}{16}$ |
| $1\frac{7}{8}$ | 2.761 | $2\frac{15}{16}$ | $3\frac{13}{32}$ | 7.475 | $1\frac{15}{32}$ | 4 | $2\frac{15}{16}$ | $4\frac{5}{32}$ | 8.629 | $1\frac{15}{32}$ | $4\frac{19}{32}$ |
| 2 | 3.142 | $3\frac{1}{8}$ | $3\frac{19}{32}$ | 8.457 | $1\frac{9}{16}$ | $4\frac{7}{32}$ | $3\frac{1}{8}$ | $4\frac{13}{32}$ | 9.766 | $1\frac{9}{16}$ | $4\frac{7}{8}$ |
| $2\frac{1}{4}$ | 3.976 | $3\frac{1}{2}$ | $4\frac{1}{32}$ | 10.609 | $1\frac{3}{4}$ | $4\frac{11}{16}$ | $3\frac{1}{2}$ | $4\frac{15}{16}$ | 12.250 | $1\frac{3}{4}$ | $5\frac{13}{32}$ |
| $2\frac{1}{2}$ | 4.909 | $3\frac{7}{8}$ | $4\frac{15}{32}$ | 13.004 | $1\frac{15}{16}$ | $5\frac{5}{32}$ | $3\frac{7}{8}$ | $5\frac{15}{32}$ | 15.016 | $1\frac{15}{16}$ | $5\frac{15}{16}$ |
| $2\frac{3}{4}$ | 5.940 | $4\frac{1}{4}$ | $4\frac{29}{32}$ | 15.642 | $2\frac{1}{8}$ | $5\frac{19}{32}$ | $4\frac{1}{4}$ | 6 | 18.063 | $2\frac{1}{8}$ | $6\frac{15}{32}$ |
| 3 | 7.069 | $4\frac{5}{8}$ | $5\frac{11}{32}$ | 18.524 | $2\frac{5}{16}$ | $6\frac{1}{16}$ | $4\frac{5}{8}$ | $6\frac{17}{32}$ | 21.391 | $2\frac{5}{16}$ | 7 |
| $3\frac{1}{4}$ | 8.296 | 5 | $5\frac{25}{32}$ | 21.650 | $2\frac{1}{2}$ | $6\frac{17}{32}$ | 5 | $7\frac{1}{16}$ | 25.000 | $2\frac{1}{2}$ | $7\frac{17}{32}$ |
| $3\frac{1}{2}$ | 9.621 | $5\frac{3}{8}$ | $6\frac{7}{32}$ | 25.019 | $2\frac{11}{16}$ | 7 | $5\frac{3}{8}$ | $7\frac{19}{32}$ | 28.891 | $2\frac{11}{16}$ | $8\frac{1}{16}$ |
| $3\frac{3}{4}$ | 11.045 | $5\frac{3}{4}$ | $6\frac{5}{8}$ | 28.632 | $2\frac{7}{8}$ | $7\frac{15}{32}$ | $5\frac{3}{4}$ | $8\frac{1}{8}$ | 33.063 | $2\frac{7}{8}$ | $8\frac{5}{8}$ |
| 4 | 12.566 | $6\frac{1}{8}$ | $7\frac{1}{16}$ | 32.489 | $3\frac{1}{16}$ | $7\frac{15}{16}$ | $6\frac{1}{8}$ | $8\frac{21}{32}$ | 37.516 | $3\frac{1}{16}$ | $9\frac{5}{32}$ |

## Screw Ends Upset Round and Square Bars

American Bridge Co. Standard

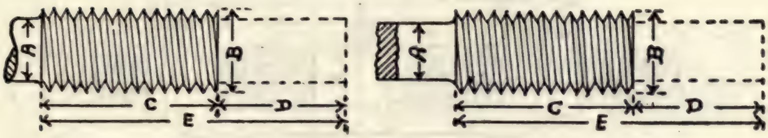



United States Standard Threads

| Screw | | | | | Round Bars Upset for A | | | | Square Bars Upset for A | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Diameter | | Area at Root of Thread B | Length | | Diam. D | Area of Round Bar | Weight | | Side E | Area of Square Bar | Weight | |
| A | Root of Thread B | | Round C | Square C | | | Screw End 1st Ft. | Round Bar per Foot | | | Screw End 1st Ft. | Square Bar per Foot |
| 1 | .84 | .55 | 4 | .. | ¾ | .44 | 2.00 | 1.50 | .. | .... | .... | .... |
| 1⅛ | .94 | .69 | .. | 4 | .. | .... | .... | .... | ¾ | .56 | 2.55 | 1.91 |
| 1¼ | 1.06 | .89 | 4 | 4 | ⅞ | .60 | 2.89 | 2.04 | ⅞ | .77 | 3.36 | 2.60 |
| 1⅜ | 1.16 | 1.05 | 4 | .. | 1 | .79 | 3.57 | 2.67 | .. | .... | .... | .... |
| 1½ | 1.28 | 1.29 | 4 | 4 | 1⅛ | .99 | 4.51 | 3.38 | 1 | 1.00 | 4.53 | 3.40 |
| 1⅝ | 1.39 | 1.52 | 4 | 4 | 1¼ | 1.23 | 5.57 | 4.17 | 1⅛ | 1.27 | 5.56 | 4.30 |
| 1¾ | 1.49 | 1.74 | 4 | .. | 1⅜ | 1.48 | 6.74 | 5.05 | .. | .... | .... | .... |
| 1⅞ | 1.62 | 2.05 | .. | 4½ | .. | .... | .... | .... | 1¼ | 1.56 | 7.30 | 5.31 |
| 2 | 1.71 | 2.30 | 4½ | 4½ | 1½ | 1.77 | 6.95 | 6.01 | 1⅜ | 1.89 | 8.57 | 6.43 |
| 2⅛ | 1.84 | 2.65 | 4½ | .. | 1⅝ | 2.07 | 9.41 | 7.05 | .. | .... | .... | .... |
| 2¼ | 1.96 | 3.02 | 5 | 5 | 1¾ | 2.41 | 10.91 | 8.18 | 1½ | 2.25 | 10.84 | 7.65 |
| 2⅜ | 2.09 | 3.42 | 5 | 5 | 1⅞ | 2.76 | 12.51 | 9.39 | 1⅝ | 2.64 | 12.34 | 8.98 |
| 2½ | 2.18 | 3.72 | 5½ | 5½ | 2 | 3.14 | 14.24 | 10.68 | 1¾ | 3.06 | 14.31 | 10.41 |
| 2⅝ | 2.30 | 4.16 | 5½ | .. | 2⅛ | 3.55 | 15.58 | 12.06 | .. | .... | .... | .... |
| 2¾ | 2.43 | 4.62 | .. | 5½ | .. | .... | .... | .... | 1⅞ | 3.52 | 16.93 | 11.95 |
| 2⅞ | 2.55 | 5.11 | 6 | 6 | 2¼ | 3.98 | 18.60 | 13.52 | 2 | 4.00 | 19.27 | 13.60 |
| 3 | 2.63 | 5.43 | 6 | 6 | 2⅜ | 4.43 | 20.71 | 15.07 | 2⅛ | 4.52 | 21.11 | 15.35 |
| 3¼ | 2.88 | 6.51 | 6½ | 6½ | 2½ | 4.91 | 24.34 | 16.69 | 2¼ | 5.06 | 25.11 | 17.21 |
| 3½ | 3.10 | 7.55 | 7 | 7 | 2¾ | 5.94 | 29.45 | 20.20 | 2⅜ | 5.64 | 29.57 | 19.18 |
| 3¾ | 3.32 | 8.64 | 7 | 7 | 2⅞ | 6.49 | 33.10 | 22.07 | 2½ | 6.25 | 33.65 | 21.25 |
| 4 | 3.57 | 9.99 | 7½ | 7½ | 3⅛ | 7.67 | 39.11 | 26.08 | 2¾ | 7.56 | 39.63 | 25.71 |

## Upset Screw End Details

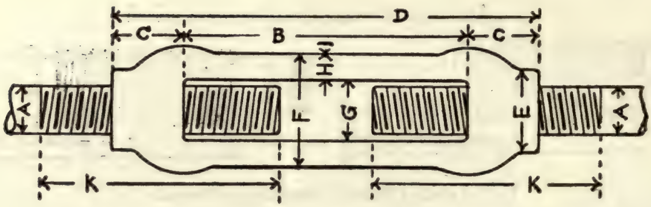
American Bridge Company Standard




United States Standard Threads

| Round Bars | | Screw | | | | | | Square Bars | | Screw | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Diam. A | Area | Diameter | | Area | | Lgth. C | Addition. Lgt. for Upset +10% | Side A | Area | Diameter | | Area | | Lgth. C | Addition. Lgt. for Upset +10% |
| | | Outside B | Root of Thd. | Root of Thd. | Ex. over Bar A % | | | | | Outside B | Root of Thd. | Root of Thd. | Excess over Bar A % | | |
| ¾ | .44 | 1 | .84 | .55 | 24.7 | 4 | 4 | .. | .. | .. | .. | .. | .. | .. | .. |
| .. | .. | .. | ... | ... | ... | .. | .. | ¾ | .56 | 1⅛ | .94 | .69 | 23.2 | 4 | 4 |
| ⅞ | .60 | 1¼ | 1.06 | .89 | 48.0 | 4 | 5 | ⅞ | .77 | 1¼ | 1.06 | .89 | 16.2 | 4 | 3½ |
| 1 | .79 | 1⅜ | 1.16 | 1.05 | 34.2 | 4 | 4 | 1 | 1.00 | 1½ | 1.28 | 1.29 | 29.4 | 4 | 4 |
| 1⅛ | .99 | 1½ | 1.28 | 1.29 | 30.2 | 4 | 4 | 1⅛ | 1.27 | 1⅝ | 1.39 | 1.52 | 19.7 | 4 | 3½ |
| 1¼ | 1.23 | 1⅝ | 1.39 | 1.52 | 23.5 | 4 | 4 | 1¼ | 1.56 | 1⅞ | 1.62 | 2.05 | 31.1 | 4½ | 4½ |
| 1⅜ | 1.49 | 1¾ | 1.49 | 1.74 | 17.5 | 4 | 4 | 1⅜ | 1.89 | 2 | 1.71 | 2.30 | 21.7 | 4½ | 4 |
| 1½ | 1.77 | 2 | 1.71 | 2.30 | 30.2 | 4½ | 4½ | 1½ | 2.25 | 2¼ | 1.96 | 3.02 | 34.3 | 5 | 5 |
| 1⅝ | 2.07 | 2⅛ | 1.84 | 2.65 | 27.7 | 4½ | 4 | 1⅝ | 2.64 | 2⅜ | 2.09 | 3.42 | 29.5 | 5 | 4½ |
| 1¾ | 2.41 | 2¼ | 1.96 | 3.02 | 25.6 | 5 | 4 | 1¾ | 3.06 | 2½ | 2.18 | 3.72 | 21.3 | 5½ | 4½ |
| 1⅞ | 2.76 | 2⅜ | 2.09 | 3.42 | 23.8 | 5 | 4 | 1⅞ | 3.52 | 2¾ | 2.43 | 4.62 | 31.4 | 5½ | 5 |
| 2 | 3.14 | 2½ | 2.18 | 3.72 | 18.3 | 5½ | 4 | 2 | 4.00 | 2⅞ | 2.55 | 5.11 | 27.7 | 6 | 5 |
| 2⅛ | 3.55 | 2⅝ | 2.30 | 4.16 | 17.2 | 5½ | 3½ | 2⅛ | 4.52 | 3 | 2.63 | 5.43 | 20.2 | 6 | 4½ |
| 2¼ | 3.98 | 2⅞ | 2.55 | 5.11 | 28.4 | 6 | 4½ | 2¼ | 5.06 | 3¼ | 2.88 | 6.51 | 28.6 | 6½ | 5½ |
| 2⅜ | 4.43 | 3 | 2.63 | 5.43 | 22.5 | 6 | 4½ | 2⅜ | 5.64 | 3½ | 3.10 | 7.55 | 33.8 | 7 | 6½ |
| 2½ | 4.91 | 3¼ | 2.88 | 6.51 | 32.6 | 6½ | 5½ | 2½ | 6.25 | 3¾ | 3.32 | 8.64 | 38.3 | 7 | 7 |
| 2⅝ | 5.41 | 3¼ | 2.88 | 6.51 | 20.3 | 6½ | 4½ | 2⅝ | 6.89 | 3¾ | 3.32 | 8.64 | 25.4 | 7 | 5½ |
| 2¾ | 5.94 | 3½ | 3.10 | 7.55 | 27.1 | 7 | 5½ | 2¾ | 7.56 | 4 | 3.57 | 9.99 | 32.1 | 7½ | 6½ |
| 2⅞ | 6.49 | 3¾ | 3.32 | 8.64 | 33.1 | 7 | 6 | 2⅞ | 8.27 | 4¼ | 3.80 | 11.3 | 37.1 | 8 | 7½ |
| 3 | 7.07 | 3¾ | 3.32 | 8.64 | 22.2 | 7 | 5 | 3 | 9.00 | 4¼ | 3.80 | 11.3 | 25.9 | 8 | 6 |
| 3⅛ | 7.67 | 4 | 3.57 | 9.99 | 30.3 | 7½ | 6 | 3⅛ | 9.77 | 4½ | 4.03 | 12.7 | 30.5 | 8½ | 7 |
| 3¼ | 8.30 | 4 | 3.57 | 9.99 | 20.5 | 7½ | 5 | 3¼ | 10.6 | 4¾ | 4.26 | 14.2 | 34.6 | 8½ | 7½ |

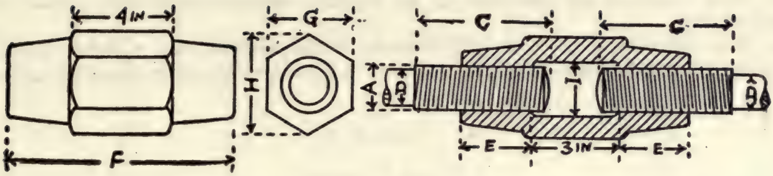
## Turnbuckles




United States Standard Threads

| Diam. of Screw A | Length | | | Diam. | Width | | Section | | Thread | Weight |
|---|---|---|---|---|---|---|---|---|---|---|
| | Open. B | Thread C | Overall D | E | F | G | H | I | K | |
| $\frac{1}{2}$ | 6 | $\frac{3}{4}$ | $7\frac{1}{2}$ | $\frac{7}{8}$ | $1\frac{1}{8}$ | $\frac{5}{8}$ | $\frac{1}{4}$ | $\frac{5}{8}$ | 4 | 1 |
| $\frac{9}{16}$ | 6 | $\frac{27}{32}$ | $7\frac{11}{16}$ | 1 | $1\frac{7}{16}$ | $\frac{13}{16}$ | $\frac{5}{16}$ | $\frac{3}{4}$ | 4 | $1\frac{1}{2}$ |
| $\frac{5}{8}$ | 6 | $\frac{15}{16}$ | $7\frac{7}{8}$ | $1\frac{1}{16}$ | $1\frac{7}{16}$ | $\frac{13}{16}$ | $\frac{5}{16}$ | $\frac{3}{4}$ | 4 | $1\frac{1}{2}$ |
| $\frac{3}{4}$ | 6 | $1\frac{1}{8}$ | $8\frac{1}{4}$ | $1\frac{1}{4}$ | $1\frac{3}{4}$ | $1\frac{1}{16}$ | $\frac{11}{32}$ | $\frac{7}{8}$ | 4 | 2 |
| $\frac{7}{8}$ | 6 | $1\frac{5}{16}$ | $8\frac{5}{8}$ | $1\frac{7}{16}$ | 2 | $1\frac{1}{4}$ | $\frac{3}{8}$ | 1 | 4 | 3 |
| 1 | 6 | $1\frac{1}{2}$ | 9 | $1\frac{5}{8}$ | $2\frac{3}{16}$ | $1\frac{5}{16}$ | $\frac{7}{16}$ | $1\frac{1}{4}$ | 4 | 4 |
| $1\frac{1}{8}$ | 6 | $1\frac{11}{16}$ | $9\frac{3}{8}$ | $1\frac{13}{16}$ | $2\frac{7}{16}$ | $1\frac{7}{16}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | 4 | 5 |
| $1\frac{1}{4}$ | 6 | $1\frac{7}{8}$ | $9\frac{3}{4}$ | 2 | $2\frac{9}{16}$ | $1\frac{9}{16}$ | $\frac{1}{2}$ | $1\frac{1}{2}$ | 4 | 6 |
| $1\frac{3}{8}$ | 6 | $2\frac{1}{16}$ | $10\frac{1}{8}$ | $2\frac{3}{16}$ | $2\frac{11}{16}$ | $1\frac{11}{16}$ | $\frac{1}{2}$ | $1\frac{5}{8}$ | 4 | 7 |
| $1\frac{1}{2}$ | 6 | $2\frac{1}{4}$ | $10\frac{1}{2}$ | $2\frac{3}{8}$ | 3 | $1\frac{3}{4}$ | $\frac{5}{8}$ | $1\frac{3}{4}$ | 4 | 8 |
| $1\frac{5}{8}$ | 6 | $2\frac{7}{16}$ | $10\frac{7}{8}$ | $2\frac{9}{16}$ | $3\frac{1}{4}$ | 2 | $\frac{5}{8}$ | $1\frac{7}{8}$ | 4 | 10 |
| $1\frac{3}{4}$ | 6 | $2\frac{5}{8}$ | $11\frac{1}{4}$ | $2\frac{3}{4}$ | $3\frac{3}{8}$ | $2\frac{1}{8}$ | $\frac{5}{8}$ | 2 | 4 | 11 |
| $1\frac{7}{8}$ | 6 | $2\frac{13}{16}$ | $11\frac{5}{8}$ | $2\frac{15}{16}$ | $3\frac{9}{16}$ | $2\frac{3}{16}$ | $\frac{11}{16}$ | $2\frac{1}{8}$ | $4\frac{1}{2}$ | 12 |
| 2 | 6 | 3 | 12 | $3\frac{1}{8}$ | $3\frac{3}{4}$ | $2\frac{3}{8}$ | $\frac{11}{16}$ | $2\frac{1}{4}$ | $4\frac{1}{2}$ | 14 |
| $2\frac{1}{8}$ | 6 | $3\frac{3}{16}$ | $12\frac{3}{8}$ | $3\frac{5}{16}$ | $3\frac{15}{16}$ | $2\frac{1}{2}$ | $\frac{23}{32}$ | $2\frac{1}{2}$ | $4\frac{1}{2}$ | 17 |
| $2\frac{1}{4}$ | 6 | $3\frac{3}{8}$ | $12\frac{3}{4}$ | $3\frac{1}{2}$ | $4\frac{5}{16}$ | $2\frac{11}{16}$ | $\frac{13}{16}$ | $2\frac{1}{2}$ | 5 | 20 |
| $2\frac{3}{8}$ | 6 | $3\frac{9}{16}$ | $13\frac{1}{8}$ | $3\frac{7}{8}$ | $4\frac{3}{8}$ | $2\frac{3}{4}$ | $\frac{13}{16}$ | $2\frac{3}{4}$ | 5 | 22 |
| $2\frac{1}{2}$ | 6 | $3\frac{3}{4}$ | $13\frac{1}{2}$ | $3\frac{7}{8}$ | $4\frac{3}{4}$ | $3\frac{1}{16}$ | $\frac{27}{32}$ | 3 | $5\frac{1}{2}$ | 25 |
| $2\frac{5}{8}$ | 6 | $4\frac{1}{8}$ | $14\frac{1}{4}$ | $4\frac{1}{4}$ | $5\frac{1}{8}$ | $3\frac{1}{4}$ | $\frac{15}{16}$ | $3\frac{1}{4}$ | $5\frac{1}{2}$ | 33 |
| $2\frac{3}{4}$ | 6 | $4\frac{1}{8}$ | $14\frac{1}{4}$ | $4\frac{1}{4}$ | $5\frac{1}{8}$ | $3\frac{1}{4}$ | $\frac{15}{16}$ | $3\frac{1}{4}$ | $5\frac{1}{2}$ | 33 |
| $2\frac{7}{8}$ | 6 | $4\frac{5}{16}$ | $14\frac{5}{8}$ | $4\frac{5}{8}$ | $5\frac{1}{2}$ | $3\frac{7}{16}$ | $1\frac{1}{32}$ | $3\frac{1}{4}$ | 6 | 36 |
| 3 | 6 | $4\frac{1}{2}$ | 15 | $4\frac{5}{8}$ | $5\frac{11}{16}$ | $3\frac{5}{8}$ | $1\frac{1}{32}$ | $3\frac{1}{2}$ | 6 | 40 |
| $3\frac{1}{4}$ | 6 | $4\frac{7}{8}$ | $15\frac{3}{4}$ | 5 | 6 | $3\frac{7}{8}$ | $1\frac{1}{16}$ | 4 | $6\frac{1}{2}$ | 50 |
| $3\frac{1}{2}$ | 6 | $5\frac{1}{4}$ | $16\frac{1}{2}$ | $5\frac{3}{8}$ | $6\frac{11}{16}$ | $4\frac{1}{4}$ | $1\frac{7}{32}$ | 4 | 7 | 65 |
| $3\frac{3}{4}$ | 6 | $5\frac{5}{8}$ | $17\frac{1}{4}$ | $5\frac{3}{4}$ | $7\frac{1}{16}$ | $4\frac{7}{16}$ | $1\frac{5}{16}$ | 5 | 7 | 95 |
| 4 | 6 | 6 | 18 | $6\frac{1}{8}$ | $7\frac{1}{2}$ | $4\frac{5}{8}$ | $1\frac{7}{16}$ | 5 | $7\frac{1}{2}$ | 108 |

## Sleeve Nuts




United States Standard Threads

| Screw Ends | | | Diam. Bar D | Thread E | Length F | Diameters | | | Weight |
|---|---|---|---|---|---|---|---|---|---|
| Diameter A | Threads per In. | Length C | | | | Short G | Long H | Inside I | |
| $\frac{7}{8}$ | 9 | 4 | $\frac{5}{8}$ | $1\frac{1}{2}$ | 7 | $1\frac{5}{8}$ | $1\frac{7}{8}$ | $1\frac{1}{8}$ | 3 |
| 1 | 8 | 4 | $\frac{3}{4}$ | $1\frac{1}{2}$ | 7 | $1\frac{5}{8}$ | $1\frac{7}{8}$ | $1\frac{1}{8}$ | 3 |
| $1\frac{1}{8}$ | 7 | 4 | $\frac{3}{4}$ | $1\frac{3}{4}$ | $7\frac{1}{2}$ | 2 | $2\frac{5}{16}$ | $1\frac{3}{8}$ | 4 |
| $1\frac{1}{4}$ | 7 | 4 | $\frac{7}{8}$ | $1\frac{3}{4}$ | $7\frac{1}{2}$ | 2 | $2\frac{5}{16}$ | $1\frac{3}{8}$ | 4 |
| $1\frac{3}{8}$ | 6 | 4 | 1 | 2 | 8 | $2\frac{3}{8}$ | $2\frac{3}{4}$ | $1\frac{5}{8}$ | 5 |
| $1\frac{1}{2}$ | 6 | 4 | $1\frac{1}{8}$ | 2 | 8 | $2\frac{3}{8}$ | $2\frac{3}{4}$ | $1\frac{5}{8}$ | 6 |
| $1\frac{5}{8}$ | $5\frac{1}{2}$ | 4 | $1\frac{1}{4}$ | $2\frac{1}{4}$ | $8\frac{1}{2}$ | $2\frac{3}{4}$ | $3\frac{3}{16}$ | $1\frac{7}{8}$ | 8 |
| $1\frac{3}{4}$ | 5 | 4 | $1\frac{3}{8}$ | $2\frac{1}{4}$ | $8\frac{1}{2}$ | $2\frac{3}{4}$ | $3\frac{3}{16}$ | $1\frac{7}{8}$ | 9 |
| $1\frac{7}{8}$ | 5 | 4 | $1\frac{3}{8}$ | $2\frac{1}{2}$ | 9 | $3\frac{1}{8}$ | $3\frac{5}{8}$ | $2\frac{1}{8}$ | 10 |
| 2 | $4\frac{1}{2}$ | $4\frac{1}{2}$ | $1\frac{1}{2}$ | $2\frac{1}{2}$ | 9 | $3\frac{1}{8}$ | $3\frac{5}{8}$ | $2\frac{1}{8}$ | 11 |
| $2\frac{1}{8}$ | $4\frac{1}{2}$ | $4\frac{1}{2}$ | $1\frac{5}{8}$ | $2\frac{3}{4}$ | $9\frac{1}{2}$ | $3\frac{1}{2}$ | $4\frac{1}{16}$ | $2\frac{3}{8}$ | 14 |
| $2\frac{1}{4}$ | $4\frac{1}{2}$ | 5 | $1\frac{3}{4}$ | $2\frac{3}{4}$ | $9\frac{1}{2}$ | $3\frac{1}{2}$ | $4\frac{1}{16}$ | $2\frac{3}{8}$ | 15 |
| $2\frac{3}{8}$ | $4\frac{1}{2}$ | 5 | $1\frac{7}{8}$ | 3 | 10 | $3\frac{7}{8}$ | $4\frac{1}{2}$ | $2\frac{5}{8}$ | 18 |
| $2\frac{1}{2}$ | 4 | $5\frac{1}{2}$ | 2 | 3 | 10 | $3\frac{7}{8}$ | $4\frac{1}{2}$ | $2\frac{5}{8}$ | 19 |
| $2\frac{5}{8}$ | 4 | $5\frac{1}{2}$ | $2\frac{1}{8}$ | $3\frac{1}{4}$ | $10\frac{1}{2}$ | $4\frac{1}{4}$ | $4\frac{15}{16}$ | $2\frac{7}{8}$ | 23 |
| $2\frac{3}{4}$ | 4 | 6 | $2\frac{1}{8}$ | $3\frac{1}{4}$ | $10\frac{1}{2}$ | $4\frac{1}{4}$ | $4\frac{15}{16}$ | $2\frac{7}{8}$ | 23 |
| $2\frac{7}{8}$ | 4 | 6 | $2\frac{1}{4}$ | $3\frac{1}{2}$ | 11 | $4\frac{5}{8}$ | $5\frac{3}{8}$ | $3\frac{1}{8}$ | 27 |
| 3 | $3\frac{1}{2}$ | 6 | $2\frac{3}{8}$ | $3\frac{1}{2}$ | 11 | $4\frac{5}{8}$ | $5\frac{3}{8}$ | $3\frac{1}{8}$ | 28 |
| $3\frac{1}{4}$ | $3\frac{1}{2}$ | $6\frac{1}{2}$ | $2\frac{1}{2}$ | $3\frac{3}{4}$ | $11\frac{1}{2}$ | 5 | $5\frac{13}{16}$ | $3\frac{3}{8}$ | 35 |
| $3\frac{1}{2}$ | $3\frac{1}{4}$ | 7 | $2\frac{3}{4}$ | 4 | 12 | $5\frac{3}{8}$ | $6\frac{1}{4}$ | $3\frac{5}{8}$ | 40 |
| $3\frac{3}{4}$ | 3 | 7 | $2\frac{7}{8}$ | $4\frac{1}{4}$ | $12\frac{1}{2}$ | $5\frac{3}{4}$ | $6\frac{11}{16}$ | $3\frac{7}{8}$ | 47 |
| 4 | 3 | $7\frac{1}{2}$ | $3\frac{1}{8}$ | $4\frac{1}{2}$ | 13 | $6\frac{1}{8}$ | $7\frac{1}{16}$ | $4\frac{1}{8}$ | 55 |

# SPECIFICATIONS FOR WASHERS

## NAVY DEPARTMENT

1. Washers to be made of wrought iron or mild steel and to be of the best commercial grade and quality, and to be so certified to by the manufacturer.

2. Each commercial package to be plainly stamped with the name of the manufacturer.

3. The diameter of the hole is the necessary requirement, and a slight variation of the gauge or outside diameter will be tolerated in the discretion of the board of inspection.

### TABLE I

PLATE WASHERS

| Diameter | Thickness, Wire Gauge | Size of Hole | Size of Bolt | Approximate Number in 100 Pounds | Diameter | Thickness, Wire Gauge | Size of Hole | Size of Bolt | Approximate Number in 100 Pounds |
|---|---|---|---|---|---|---|---|---|---|
| *Ins.* | *No.* | *Inches* | *Inch* | | *Inches* | *No.* | *Inches* | *Inches* | |
| $\frac{9}{16}$ | 18 (3-64) | $\frac{1}{4}$ | $\frac{3}{16}$ | 44,075 | $2\frac{3}{4}$ | 9 (5-32) | $1\frac{1}{4}$ | $1\frac{1}{8}$ | 520 |
| $\frac{3}{4}$ | 16 (1-16) | $\frac{5}{16}$ | $\frac{1}{4}$ | 13,900 | 3 | 9 (5-32) | $1\frac{3}{8}$ | $1\frac{1}{4}$ | 400 |
| $\frac{7}{8}$ | 16 (1-16) | $\frac{3}{8}$ | $\frac{5}{16}$ | 11,250 | $3\frac{1}{4}$ | 8 (11-64) | $1\frac{1}{2}$ | $1\frac{3}{8}$ | 320 |
| 1 | 14 (5-64) | $\frac{7}{16}$ | $\frac{3}{8}$ | 6,570 | $3\frac{1}{2}$ | 8 (11-64) | $1\frac{5}{8}$ | $1\frac{1}{2}$ | 275 |
| $1\frac{1}{4}$ | 14 (5-64) | $\frac{1}{2}$ | $\frac{7}{16}$ | 4,300 | $3\frac{3}{4}$ | 8 (11-64) | $1\frac{3}{4}$ | $1\frac{5}{8}$ | 245 |
| $1\frac{3}{8}$ | 12 (3-32) | $\frac{9}{16}$ | $\frac{1}{2}$ | 2,680 | 4 | 8 (11-64) | $1\frac{7}{8}$ | $1\frac{3}{4}$ | 220 |
| $1\frac{1}{2}$ | 12 (3-32) | $\frac{5}{8}$ | $\frac{9}{16}$ | 2,250 | $4\frac{1}{4}$ | 8 (11-64) | 2 | $1\frac{7}{8}$ | 200 |
| $1\frac{3}{4}$ | 10 (1-8) | $\frac{11}{16}$ | $\frac{5}{8}$ | 1,300 | $4\frac{1}{2}$ | 8 (11-64) | $2\frac{1}{8}$ | 2 | 180 |
| 2 | 10 (1-8) | $\frac{13}{16}$ | $\frac{3}{4}$ | 1,010 | $4\frac{3}{4}$ | 6 (7-32) | $2\frac{3}{8}$ | $2\frac{1}{4}$ | 110 |
| $2\frac{1}{4}$ | 9 (5-32) | $\frac{15}{16}$ | $\frac{7}{8}$ | 860 | 5 | 6 (7-32) | $2\frac{5}{8}$ | $2\frac{1}{2}$ | 91 |
| $2\frac{1}{2}$ | 9 (5-32) | $1\frac{1}{16}$ | 1 | 625 | | | | | |

### TABLE II

PLATE WASHERS (ADDITIONAL SIZES)

| Diameter | Thickness, Wire Gauge | Size of Hole | Size of Bolt | Approximate Number in 100 Pounds | Diameter | Thickness, Wire Gauge | Size of Hole | Size of Bolt | Approximate Number in 100 Pounds |
|---|---|---|---|---|---|---|---|---|---|
| *Ins.* | *No.* | *Inch* | *Inch* | | *Inches* | *No.* | *Inches* | *Inches* | |
| $\frac{1}{2}$ | 18 | $\frac{1}{4}$ | $\frac{3}{16}$ | 45,500 | $1\frac{1}{4}$ | 12 | $\frac{5}{8}$ | $\frac{9}{16}$ | 3,900 |
| $\frac{5}{8}$ | 16 | $\frac{5}{16}$ | $\frac{1}{4}$ | 21,500 | $1\frac{3}{8}$ | 12 | $\frac{5}{8}$ | $\frac{9}{16}$ | 3,000 |
| $\frac{3}{4}$ | 16 | $\frac{3}{8}$ | $\frac{5}{16}$ | 16,500 | $1\frac{1}{4}$ | 12 | $\frac{11}{16}$ | $\frac{5}{8}$ | 4,100 |
| $\frac{7}{8}$ | 14 | $\frac{7}{16}$ | $\frac{3}{8}$ | 11,500 | $1\frac{3}{8}$ | 12 | $\frac{11}{16}$ | $\frac{5}{8}$ | 3,200 |
| 1 | 14 | $\frac{1}{2}$ | $\frac{7}{16}$ | 7,400 | $1\frac{1}{2}$ | 10 | $\frac{11}{16}$ | $\frac{5}{8}$ | 2,150 |
| $1\frac{1}{8}$ | 14 | $\frac{1}{2}$ | $\frac{7}{16}$ | 5,450 | $1\frac{1}{2}$ | 10 | $\frac{13}{16}$ | $\frac{3}{4}$ | 2,200 |
| $1\frac{1}{8}$ | 12 | $\frac{9}{16}$ | $\frac{1}{2}$ | 4,800 | $1\frac{3}{4}$ | 10 | $\frac{13}{16}$ | $\frac{3}{4}$ | 1,400 |
| $1\frac{1}{4}$ | 12 | $\frac{9}{16}$ | $\frac{1}{2}$ | 3,650 | 2 | 9 | $\frac{15}{16}$ | $\frac{7}{8}$ | 1,150 |
| $1\frac{1}{2}$ | 12 | $\frac{9}{16}$ | $\frac{1}{2}$ | 2,000 | $2\frac{1}{4}$ | 9 | $1\frac{1}{16}$ | 1 | 940 |

## TABLE III

### Plate Washers (Extra Sizes)

| Diameter | Thickness, Wire Gauge | Size of Hole | Size of Bolt | Diameter | Thickness, Wire Gauge | Size of Hole | Size of Bolt |
|---|---|---|---|---|---|---|---|
| *Inches* | *No.* | *Inches* | *Inches* | *Inches* | *No.* | *Inches* | *Inches* |
| $\frac{9}{16}$ | 16 | $\frac{5}{16}$ | $\frac{1}{4}$ | 2 | 9 | $1\frac{1}{16}$ | 1 |
| $\frac{3}{4}$ | 16 | $\frac{7}{16}$ | $\frac{3}{8}$ | 2 | 9 | $1\frac{1}{4}$ | $1\frac{1}{8}$ |
| $\frac{7}{8}$ | 14 | $\frac{1}{2}$ | $\frac{7}{16}$ | $2\frac{1}{4}$ | 9 | $1\frac{1}{4}$ | $1\frac{1}{8}$ |
| 1 | 14 | $\frac{9}{16}$ | $\frac{1}{2}$ | $2\frac{1}{2}$ | 9 | $1\frac{1}{4}$ | $1\frac{1}{8}$ |
| $1\frac{1}{16}$ | 12 | $\frac{9}{16}$ | $\frac{1}{2}$ | $2\frac{1}{2}$ | 9 | $1\frac{3}{8}$ | $1\frac{1}{4}$ |
| $1\frac{1}{8}$ | 12 | $\frac{11}{16}$ | $\frac{5}{8}$ | $2\frac{3}{4}$ | 9 | $1\frac{3}{8}$ | $1\frac{1}{4}$ |
| $1\frac{5}{8}$ | 10 | $\frac{11}{16}$ | $\frac{5}{8}$ | 3 or $3\frac{1}{4}$ | 9 | $1\frac{1}{2}$ | $1\frac{3}{8}$ |
| $1\frac{3}{8}$ | 10 | $\frac{13}{16}$ | $\frac{3}{4}$ | 3 | 8 | $1\frac{5}{8}$ | $1\frac{1}{2}$ |
| $1\frac{5}{8}$ | 10 | $\frac{13}{16}$ | $\frac{3}{4}$ | $3\frac{1}{4}$ or $3\frac{1}{2}$ | 8 | $1\frac{5}{8}$ | $1\frac{1}{2}$ |
| $1\frac{3}{4}$ | 10 | $\frac{15}{16}$ | $\frac{7}{8}$ | $3\frac{1}{2}$ | 8 | $1\frac{7}{8}$ | $1\frac{3}{4}$ |
| $1\frac{7}{8}$ | 10 | $\frac{15}{16}$ | $\frac{7}{8}$ | $3\frac{3}{4}$ | 8 | $1\frac{7}{8}$ | $1\frac{3}{4}$ |
| $1\frac{3}{4}$ | 10 | $1\frac{1}{16}$ | 1 | 4 | 8 | $2\frac{1}{8}$ | 2 |

## TABLE IV

### Square Washers

| Wide | Thick. | Hole | Bolt | Approximate Number in 100 Pounds | Wide | Thick. | Hole | Bolt | Approximate Number in 100 Pounds |
|---|---|---|---|---|---|---|---|---|---|
| *Ins.* | *Inch* | *Inches* | *Inches* | | *Inches* | *Inch* | *Inches* | *Inches* | |
| $1\frac{1}{2}$ | $\frac{1}{8}$ | $\frac{7}{16}$ | $\frac{3}{8}$ | 1,300 | 4 | $\frac{3}{8}$ | $1\frac{1}{4}$ | $1\frac{1}{8}$ | 65 |
| $1\frac{3}{4}$ | $\frac{1}{8}$ | $\frac{1}{2}$ | $\frac{7}{16}$ | 1,100 | $4\frac{1}{2}$ | $\frac{3}{8}$ | $1\frac{3}{8}$ | $1\frac{1}{4}$ | 48 |
| 2 | $\frac{3}{16}$ | $\frac{9}{16}$ | $\frac{1}{2}$ | 500 | 5 | $\frac{3}{8}$ | $1\frac{1}{2}$ | $1\frac{3}{8}$ | 40 |
| $2\frac{1}{4}$ | $\frac{1}{4}$ | $\frac{23}{32}$ | $\frac{5}{8}$ | 315 | 6 | $\frac{3}{8}$ | $1\frac{5}{8}$ | $1\frac{1}{2}$ | 28 |
| $2\frac{1}{2}$ | $\frac{1}{4}$ | $\frac{27}{32}$ | $\frac{3}{4}$ | 250 | $6\frac{1}{2}$ | $\frac{3}{8}$ | $1\frac{7}{8}$ | $1\frac{3}{4}$ | 24 |
| 3 | $\frac{1}{4}$ | $\frac{31}{32}$ | $\frac{7}{8}$ | 165 | 7 | $\frac{3}{8}$ | $2\frac{1}{8}$ | 2 | 21 |
| $3\frac{1}{2}$ | $\frac{3}{8}$ | $1\frac{3}{32}$ | 1 | 87 | | | | | |

# BRASS WASHERS

## NAVY DEPARTMENT

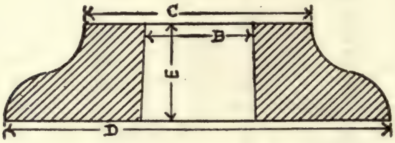
1. To be made from sheet brass, smoothly punched, without burrs.
2. Sizes to be as specified. The following sizes are those most commonly used:

| Outside Diameter | Inside Diameter | Thickness | Outside Diameter | Inside Diameter | Thickness |
|---|---|---|---|---|---|
| *Inches* | *Inch* | *Inch* | *Inches* | *Inch* | *Inch* |
| $\frac{1}{2}$ | $\frac{3}{16}$ | 0.065 | $1\frac{3}{8}$ | $\frac{9}{16}$ | .083 |
| $\frac{9}{16}$ | $\frac{1}{4}$ | .042 | $1\frac{1}{2}$ | $\frac{5}{8}$ | .083 |
| $\frac{3}{4}$ | $\frac{5}{16}$ | .053 | $1\frac{3}{4}$ | $\frac{11}{16}$ | .106 |
| $\frac{7}{8}$ | $\frac{3}{8}$ | .053 | 2 | $\frac{3}{4}$ | .103 |
| $1\frac{1}{4}$ | $\frac{1}{2}$ | .063 | $2\frac{1}{2}$ | $\frac{7}{8}$ | .115 |

3. To be packed in well-made wooden boxes, one size of washer per box, each box marked with the name of the material, the quantity, size, and the name of the manufacturer.

4. Each delivery to be marked with the name of the material, the name of the contractor, and the requisition or contract number under which the delivery is made.

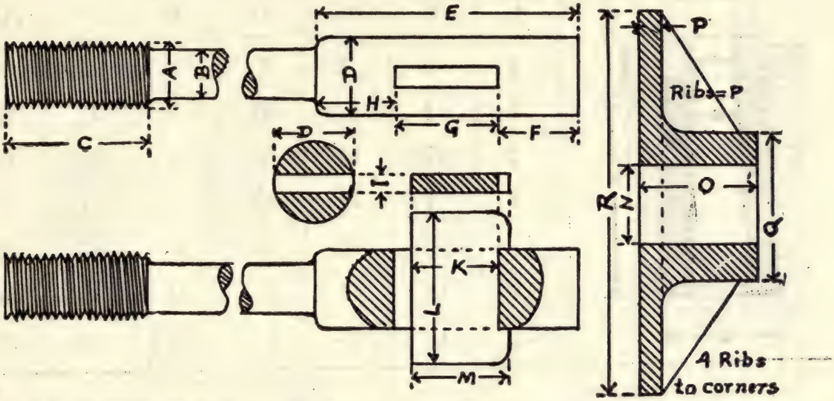
CAST IRON WASHERS




| Diameter of Bolt A | Diameter Hole B | Diameter Top C | Diameter Bottom D | Area Bottom D | Thickness E | Approx. Weight Each | Approx. Number in 100 Pounds |
|---|---|---|---|---|---|---|---|
| 1/2 | 5/8 | 1 1/2 | 2 | 3.14 | 1/2 | 0.20 | 500 |
| 5/8 | 3/4 | 1 3/4 | 2 1/2 | 4.91 | 5/8 | .40 | 250 |
| 3/4 | 7/8 | 2 | 3 | 7.07 | 3/4 | .69 | 144 |
| 7/8 | 1 | 2 1/4 | 3 1/2 | 9.62 | 7/8 | 1.10 | 91 |
| 1 | 1 1/8 | 2 1/2 | 4 | 12.57 | 1 | 1.64 | 61 |
| 1 1/8 | 1 1/4 | 2 3/4 | 4 1/2 | 15.90 | 1 1/8 | 2.33 | 43 |
| 1 1/4 | 1 3/8 | 3 | 5 | 19.64 | 1 1/4 | 3.20 | 31 |
| 1 3/8 | 1 1/2 | 3 1/4 | 5 1/2 | 23.76 | 1 3/8 | 4.25 | 23 |
| 1 1/2 | 1 5/8 | 3 1/2 | 6 | 28.27 | 1 1/2 | 5.52 | 18 |
| 1 5/8 | 1 3/4 | 3 3/4 | 6 1/2 | 33.18 | 1 5/8 | 7.02 | 14 |
| 1 3/4 | 1 7/8 | 4 | 7 | 38.48 | 1 3/4 | 8.76 | 11 |
| 1 7/8 | 2 | 4 1/4 | 7 1/2 | 44.18 | 1 7/8 | 10.79 | 9 |
| 2 | 2 1/8 | 4 1/2 | 8 | 50.27 | 2 | 13.10 | 7 |

## Foundation Bolts

### Upset Screw and Cotter Heads, and Cast Iron Washers

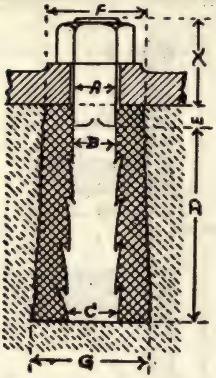



| Screw | | Bar | Dia. | Length | | | | Wdt. | Cotter | | | Washer | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Diam. A | Lgth. C | B | D | E | F | G | H | I | K | L | M | Dia. N | Dep. O | Th'k P | Dia. Q | Sq. R |
| 1 1/2 | 4 | 1 1/8 | 1 3/4 | 6 | 2 | 2 3/8 | 2 | 7/16 | 2 | 3 3/4 | 2 1/4 | 1 7/8 | 3 | 1/2 | 3 3/4 | 9 |
| 1 5/8 | 4 | 1 1/4 | 1 7/8 | 6 7/8 | 2 1/8 | 2 5/8 | 2 1/8 | 7/16 | 2 1/8 | 4 | 2 3/8 | 2 | 3 1/4 | 1/2 | 4 | 10 |
| 1 3/4 | 4 | 1 3/8 | 2 1/8 | 7 3/8 | 2 1/4 | 2 7/8 | 2 1/4 | 1/2 | 2 3/8 | 4 1/4 | 2 5/8 | 2 1/4 | 3 3/8 | 9/16 | 4 1/4 | 11 |
| 1 7/8 | 4 1/2 | 1 3/8 | 2 1/4 | 7 3/4 | 2 3/8 | 3 | 2 3/8 | 9/16 | 2 1/2 | 4 3/8 | 2 3/4 | 2 3/8 | 3 1/2 | 9/16 | 4 3/8 | 11 |
| 2 | 4 1/2 | 1 1/2 | 2 3/8 | 8 1/4 | 2 1/2 | 3 1/4 | 2 1/2 | 9/16 | 2 3/4 | 4 5/8 | 3 | 2 1/2 | 3 5/8 | 5/8 | 4 5/8 | 12 |
| 2 1/8 | 4 1/2 | 1 5/8 | 2 1/2 | 8 3/8 | 2 1/2 | 3 3/8 | 2 1/2 | 5/8 | 2 7/8 | 4 7/8 | 3 1/8 | 2 5/8 | 3 3/4 | 5/8 | 4 7/8 | 13 |
| 2 1/4 | 5 | 1 3/4 | 2 5/8 | 8 3/4 | 2 5/8 | 3 1/2 | 2 5/8 | 5/8 | 3 | 5 | 3 1/4 | 2 3/4 | 4 | 11/16 | 5 | 14 |
| 2 3/8 | 5 | 1 7/8 | 2 3/4 | 9 1/4 | 2 3/4 | 3 3/4 | 2 3/4 | 11/16 | 3 1/8 | 5 1/4 | 3 3/8 | 2 7/8 | 4 1/8 | 11/16 | 5 1/4 | 14 |
| 2 1/2 | 5 1/2 | 2 | 2 7/8 | 9 1/4 | 2 3/4 | 3 3/4 | 2 3/4 | 11/16 | 3 1/4 | 5 1/2 | 3 1/2 | 3 | 4 1/4 | 3/4 | 5 1/2 | 15 |
| 2 5/8 | 5 1/2 | 2 1/8 | 3 | 9 3/4 | 2 7/8 | 4 | 2 7/8 | 3/4 | 3 1/2 | 5 3/4 | 3 3/4 | 3 1/8 | 4 3/8 | 3/4 | 5 3/4 | 16 |
| 2 3/4 | 5 1/2 | 2 1/8 | 3 1/8 | 10 1/4 | 3 | 4 1/4 | 3 | 3/4 | 3 5/8 | 5 7/8 | 3 7/8 | 3 1/4 | 4 1/2 | 3/4 | 5 7/8 | 17 |
| 2 7/8 | 6 | 2 1/4 | 3 1/4 | 10 5/8 | 3 1/8 | 4 3/8 | 3 1/8 | 13/16 | 3 3/4 | 6 1/8 | 4 | 3 3/8 | 4 5/8 | 13/16 | 6 1/8 | 17 |
| 3 | 6 | 2 3/8 | 3 1/2 | 11 1/8 | 3 1/4 | 4 5/8 | 3 1/4 | 7/8 | 4 | 6 1/4 | 4 1/4 | 3 5/8 | 4 3/4 | 13/16 | 6 1/4 | 18 |
| 3 1/4 | 6 1/2 | 2 1/2 | 3 3/4 | 11 3/4 | 3 3/8 | 5 | 3 3/8 | 15/16 | 4 1/4 | 6 3/4 | 4 1/2 | 3 7/8 | 5 | 7/8 | 6 3/4 | 20 |
| 3 1/2 | 7 | 2 3/4 | 4 | 12 1/2 | 3 5/8 | 5 1/4 | 3 5/8 | 1 | 4 5/8 | 7 1/8 | 4 7/8 | 4 1/8 | 5 3/8 | 7/8 | 6 7/8 | 21 |
| 3 3/4 | 7 | 2 7/8 | 4 1/4 | 13 1/8 | 3 3/4 | 5 5/8 | 3 3/4 | 1 1/16 | 5 | 7 5/8 | 5 1/4 | 4 3/8 | 5 1/2 | 1 | 7 5/8 | 22 |
| 4 | 7 1/2 | 3 1/8 | 4 1/2 | 14 | 4 | 6 | 4 | 1 1/8 | 5 1/4 | 8 | 5 1/2 | 4 5/8 | 6 | 1 | 8 | 24 |

### Foundation Bolts

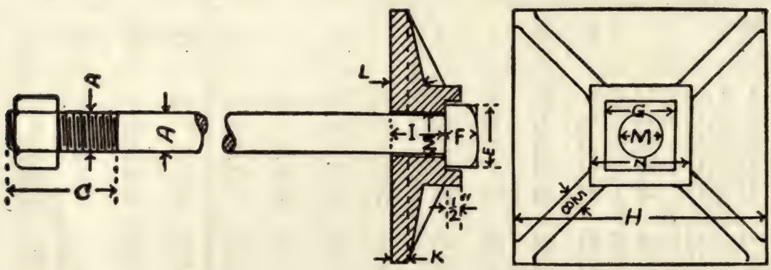
Foundation bolts for heavy machinery should not be leaded into cap stones if it can be avoided, even though the cap stones be of considerable depth or weight and anchored to foundation below. If such bolts are required merely to fix a self-contained machine in position, no vibratory strains being transmitted to the bolts, there is no objection to their use, but foundation bolts proper should extend to bottom of masonry or concrete. The illustration at top of page 408 shows a bolt with tapering head much wider at the bottom than at the neck. The cavity in the stone cap is similarly widened at the bottom. The bolt-head is jagged to secure a firmer hold on the lead filling which is poured into the cavity and around the bolt after the latter has been correctly located.

## Foundation Bolts




| Diam. A | Square B | C | D | E | F | G |
|---|---|---|---|---|---|---|
| $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{3}{4}$ | 2 | $\frac{1}{2}$ | 1 | $1\frac{1}{4}$ |
| $\frac{5}{8}$ | $\frac{5}{8}$ | 1 | $2\frac{1}{2}$ | $\frac{5}{8}$ | $1\frac{1}{4}$ | $1\frac{1}{2}$ |
| $\frac{3}{4}$ | $\frac{3}{4}$ | $1\frac{1}{8}$ | 3 | $\frac{3}{4}$ | $1\frac{1}{2}$ | $1\frac{3}{4}$ |
| $\frac{7}{8}$ | $\frac{7}{8}$ | $1\frac{1}{4}$ | $3\frac{1}{2}$ | $\frac{7}{8}$ | $1\frac{5}{8}$ | 2 |
| 1 | 1 | $1\frac{1}{2}$ | 4 | 1 | $1\frac{7}{8}$ | $2\frac{1}{4}$ |
| $1\frac{1}{8}$ | $1\frac{1}{8}$ | $1\frac{3}{4}$ | 5 | $1\frac{1}{8}$ | $2\frac{1}{4}$ | $2\frac{3}{8}$ |
| $1\frac{1}{4}$ | $1\frac{1}{4}$ | 2 | 6 | $1\frac{1}{4}$ | $2\frac{3}{8}$ | $2\frac{5}{8}$ |

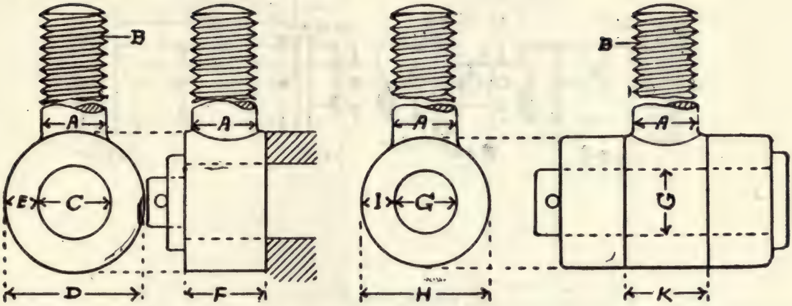
## Foundation Bolts and Cast Iron Washers




### United States Standard Bolts

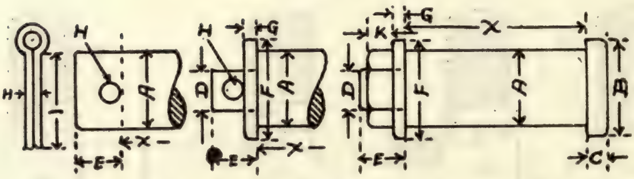
| Screw | | Bolt-Head | | Washer | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Diam. A | Length C | Short Diam. E | Thick. F | Side of Square G | Side of Square H | Depth I | Thickness K | Thickness L | Diam. Hole M | Side of Square N |
| $\frac{3}{4}$ | $2\frac{1}{4}$ | $1\frac{1}{4}$ | $\frac{5}{8}$ | $1\frac{1}{2}$ | 6 | $1\frac{1}{4}$ | $\frac{1}{4}$ | $\frac{5}{8}$ | $\frac{7}{8}$ | $2\frac{1}{4}$ |
| $\frac{7}{8}$ | $2\frac{1}{2}$ | $1\frac{7}{16}$ | $\frac{3}{4}$ | $1\frac{11}{16}$ | $6\frac{1}{2}$ | $1\frac{3}{8}$ | $\frac{1}{4}$ | $\frac{11}{16}$ | 1 | $2\frac{7}{16}$ |
| 1 | 3 | $1\frac{5}{8}$ | $\frac{13}{16}$ | $1\frac{7}{8}$ | 7 | $1\frac{1}{2}$ | $\frac{3}{8}$ | $\frac{3}{4}$ | $1\frac{1}{8}$ | $2\frac{5}{8}$ |
| $1\frac{1}{8}$ | $3\frac{1}{4}$ | $1\frac{13}{16}$ | $\frac{15}{16}$ | $2\frac{1}{16}$ | $7\frac{1}{2}$ | $1\frac{5}{8}$ | $\frac{3}{8}$ | $\frac{13}{16}$ | $1\frac{1}{4}$ | $2\frac{13}{16}$ |
| $1\frac{1}{4}$ | $3\frac{1}{2}$ | 2 | 1 | $2\frac{1}{4}$ | 8 | $1\frac{3}{4}$ | $\frac{3}{8}$ | $\frac{7}{8}$ | $1\frac{3}{8}$ | $3\frac{1}{4}$ |
| $1\frac{3}{8}$ | $3\frac{3}{4}$ | $2\frac{3}{16}$ | $1\frac{1}{8}$ | $2\frac{7}{16}$ | $8\frac{1}{2}$ | $1\frac{7}{8}$ | $\frac{3}{8}$ | $\frac{15}{16}$ | $1\frac{1}{2}$ | $3\frac{7}{16}$ |
| $1\frac{1}{2}$ | 4 | $2\frac{3}{8}$ | $1\frac{13}{16}$ | $2\frac{5}{8}$ | 9 | 2 | $\frac{1}{2}$ | 1 | $1\frac{5}{8}$ | $3\frac{5}{8}$ |
| $1\frac{5}{8}$ | 4 | $2\frac{9}{16}$ | $1\frac{5}{16}$ | $2\frac{13}{16}$ | 10 | $2\frac{1}{8}$ | $\frac{1}{2}$ | $1\frac{1}{16}$ | $1\frac{3}{4}$ | $3\frac{13}{16}$ |
| $1\frac{3}{4}$ | 4 | $2\frac{3}{4}$ | $1\frac{3}{8}$ | 3 | 11 | $2\frac{1}{4}$ | $\frac{1}{2}$ | $1\frac{1}{8}$ | $1\frac{7}{8}$ | 4 |
| $1\frac{7}{8}$ | $4\frac{1}{2}$ | $2\frac{15}{16}$ | $1\frac{1}{2}$ | $3\frac{3}{16}$ | 11 | $2\frac{3}{8}$ | $\frac{1}{2}$ | $1\frac{3}{16}$ | 2 | $4\frac{3}{16}$ |
| 2 | $4\frac{1}{2}$ | $3\frac{1}{8}$ | $1\frac{9}{16}$ | $3\frac{3}{8}$ | 12 | $2\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | $2\frac{1}{8}$ | $4\frac{3}{8}$ |

## Eye Bolt Head




| Bar | | Screw | | Eye Bolt Head | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dia. A | Area | Diam. Root of Thread B | Area | Diam. C | Diam. D | Th'k-ness E | Width F | Area EXF | Diam. G | Diam. H | Th'k-ness I | Width K | Area IXK |
| $\frac{1}{2}$ | .196 | .400 | .125 | $\frac{9}{16}$ | 1 | $\frac{7}{32}$ | $\frac{5}{8}$ | .137 | $\frac{9}{16}$ | 1 | $\frac{7}{32}$ | $\frac{5}{8}$ | .137 |
| $\frac{9}{16}$ | .249 | .454 | .162 | $\frac{5}{8}$ | $1\frac{1}{8}$ | $\frac{1}{4}$ | $\frac{11}{16}$ | .172 | $\frac{5}{8}$ | $1\frac{1}{8}$ | $\frac{1}{4}$ | $\frac{11}{16}$ | .172 |
| $\frac{5}{8}$ | .307 | .507 | .202 | $\frac{3}{4}$ | $1\frac{3}{8}$ | $\frac{5}{16}$ | $\frac{13}{16}$ | .254 | $\frac{11}{16}$ | $1\frac{5}{16}$ | $\frac{5}{16}$ | $\frac{3}{4}$ | .234 |
| $\frac{3}{4}$ | .442 | .620 | .302 | $\frac{7}{8}$ | $1\frac{5}{8}$ | $\frac{3}{8}$ | $\frac{15}{16}$ | .352 | $\frac{13}{16}$ | $1\frac{9}{16}$ | $\frac{3}{8}$ | $\frac{15}{16}$ | .352 |
| $\frac{7}{8}$ | .601 | .731 | .419 | 1 | $1\frac{7}{8}$ | $\frac{7}{16}$ | $1\frac{1}{8}$ | .492 | $\frac{7}{8}$ | $1\frac{3}{4}$ | $\frac{7}{16}$ | $1\frac{1}{8}$ | .492 |
| 1 | .785 | .837 | .550 | $1\frac{1}{8}$ | $2\frac{1}{8}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | .625 | 1 | 2 | $\frac{1}{2}$ | $1\frac{1}{4}$ | .625 |
| $1\frac{1}{8}$ | .994 | .940 | .694 | $1\frac{5}{16}$ | $2\frac{7}{16}$ | $\frac{9}{16}$ | $1\frac{3}{8}$ | .773 | $1\frac{1}{8}$ | $2\frac{1}{4}$ | $\frac{9}{16}$ | $1\frac{3}{8}$ | .773 |
| $1\frac{1}{4}$ | 1.227 | 1.065 | .891 | $1\frac{7}{16}$ | $2\frac{13}{16}$ | $\frac{11}{16}$ | $1\frac{1}{2}$ | 1.031 | $1\frac{1}{4}$ | $2\frac{5}{8}$ | $\frac{11}{16}$ | $1\frac{1}{2}$ | 1.031 |
| $1\frac{3}{8}$ | 1.485 | 1.160 | 1.057 | $1\frac{9}{16}$ | $3\frac{1}{16}$ | $\frac{3}{4}$ | $1\frac{11}{16}$ | 1.266 | $1\frac{3}{8}$ | $2\frac{7}{8}$ | $\frac{3}{4}$ | $1\frac{11}{16}$ | 1.266 |
| $1\frac{1}{2}$ | 1.767 | 1.284 | 1.294 | $1\frac{3}{4}$ | $3\frac{3}{8}$ | $\frac{13}{16}$ | $1\frac{13}{16}$ | 1.473 | $1\frac{1}{2}$ | $3\frac{1}{8}$ | $1\frac{13}{16}$ | $1\frac{13}{16}$ | 1.473 |
| $1\frac{5}{8}$ | 2.074 | 1.389 | 1.515 | $1\frac{7}{8}$ | $3\frac{5}{8}$ | $\frac{7}{8}$ | $1\frac{15}{16}$ | 1.695 | $1\frac{5}{8}$ | $3\frac{3}{8}$ | $\frac{7}{8}$ | $1\frac{15}{16}$ | 1.695 |
| $1\frac{3}{4}$ | 2.405 | 1.491 | 1.746 | 2 | $3\frac{7}{8}$ | $\frac{15}{16}$ | $2\frac{1}{8}$ | 1.992 | $1\frac{3}{4}$ | $3\frac{5}{8}$ | $\frac{15}{16}$ | $2\frac{1}{8}$ | 1.992 |
| $1\frac{7}{8}$ | 2.761 | 1.616 | 2.051 | $2\frac{3}{16}$ | $4\frac{3}{16}$ | 1 | $2\frac{1}{4}$ | 2.250 | $1\frac{7}{8}$ | $3\frac{7}{8}$ | 1 | $2\frac{1}{4}$ | 2.250 |
| 2 | 3.142 | 1.712 | 2.302 | $2\frac{5}{16}$ | $4\frac{7}{16}$ | $1\frac{1}{16}$ | $2\frac{3}{8}$ | 2.523 | 2 | $4\frac{1}{8}$ | $1\frac{1}{16}$ | $2\frac{3}{8}$ | 2.523 |
| $2\frac{1}{4}$ | 3.976 | 1.962 | 3.023 | $2\frac{5}{8}$ | $5\frac{1}{8}$ | $1\frac{1}{4}$ | $2\frac{5}{8}$ | 3.281 | $2\frac{1}{4}$ | $4\frac{3}{4}$ | $1\frac{1}{4}$ | $2\frac{5}{8}$ | 3.281 |
| $2\frac{1}{2}$ | 4.909 | 2.176 | 3.719 | $2\frac{7}{8}$ | $5\frac{5}{8}$ | $1\frac{3}{8}$ | 3 | 4.125 | $2\frac{1}{2}$ | $5\frac{1}{4}$ | $1\frac{3}{8}$ | 3 | 4.125 |
| $2\frac{3}{4}$ | 5.940 | 2.426 | 4.622 | $3\frac{1}{4}$ | $6\frac{1}{4}$ | $1\frac{1}{2}$ | $3\frac{1}{4}$ | 4.875 | $2\frac{3}{4}$ | $5\frac{3}{4}$ | $1\frac{1}{2}$ | $3\frac{1}{4}$ | 4.875 |
| 3 | 7.069 | 2.676 | 5.624 | $3\frac{1}{2}$ | $6\frac{3}{4}$ | $1\frac{5}{8}$ | $3\frac{1}{2}$ | 5.688 | 3 | $6\frac{1}{4}$ | $1\frac{5}{8}$ | $3\frac{1}{2}$ | 5.688 |

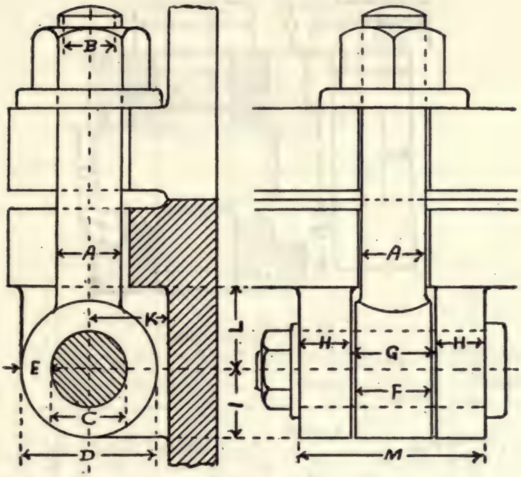
## Eye Bolt Pins in Double Shear




### Without end thrust

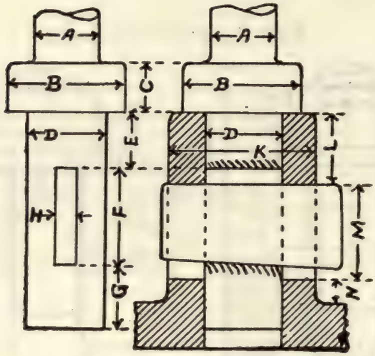
| Diameter A | B | C | D | E | F | G | H | I | K |
|---|---|---|---|---|---|---|---|---|---|
| $\frac{1}{2}$ | $\frac{3}{4}$ | $\frac{3}{16}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $\frac{3}{4}$ | $\frac{1}{8}$ | $\frac{1}{8}$ | $\frac{5}{8}$ | $\frac{1}{4}$ |
| $\frac{5}{8}$ | $\frac{7}{8}$ | $\frac{7}{32}$ | $\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{7}{8}$ | $\frac{1}{8}$ | $\frac{1}{8}$ | $\frac{3}{4}$ | $\frac{1}{4}$ |
| $\frac{3}{4}$ | 1 | $\frac{1}{4}$ | $\frac{1}{2}$ | $\frac{9}{16}$ | 1 | $\frac{1}{8}$ | $\frac{5}{32}$ | $\frac{15}{16}$ | $\frac{5}{16}$ |
| $\frac{7}{8}$ | $1\frac{3}{16}$ | $\frac{23}{32}$ | $\frac{9}{16}$ | $\frac{9}{16}$ | $1\frac{3}{16}$ | $\frac{1}{8}$ | $\frac{5}{32}$ | $1\frac{1}{16}$ | $\frac{5}{16}$ |
| 1 | $1\frac{5}{16}$ | $\frac{5}{16}$ | $\frac{5}{8}$ | $\frac{5}{8}$ | $1\frac{5}{16}$ | $\frac{5}{32}$ | $\frac{3}{16}$ | $1\frac{1}{4}$ | $\frac{3}{8}$ |
| $1\frac{1}{8}$ | $1\frac{7}{16}$ | $\frac{5}{16}$ | $\frac{5}{8}$ | $\frac{5}{8}$ | $1\frac{7}{16}$ | $\frac{5}{32}$ | $\frac{3}{16}$ | $1\frac{3}{8}$ | $\frac{3}{8}$ |
| $1\frac{1}{4}$ | $1\frac{9}{16}$ | $\frac{3}{8}$ | $\frac{3}{4}$ | $\frac{11}{16}$ | $1\frac{9}{16}$ | $\frac{5}{32}$ | $\frac{3}{16}$ | $1\frac{1}{2}$ | $\frac{3}{8}$ |
| $1\frac{3}{8}$ | $1\frac{3}{4}$ | $\frac{3}{8}$ | $\frac{3}{4}$ | $\frac{11}{16}$ | $1\frac{3}{4}$ | $\frac{5}{32}$ | $\frac{7}{32}$ | $1\frac{11}{16}$ | $\frac{7}{16}$ |
| $1\frac{1}{2}$ | $1\frac{7}{8}$ | $\frac{7}{16}$ | $\frac{3}{4}$ | $\frac{3}{4}$ | $1\frac{7}{8}$ | $\frac{3}{16}$ | $\frac{7}{32}$ | $1\frac{13}{16}$ | $\frac{7}{16}$ |
| $1\frac{5}{8}$ | 2 | $\frac{7}{16}$ | $\frac{7}{8}$ | $\frac{3}{4}$ | 2 | $\frac{3}{16}$ | $\frac{7}{32}$ | 2 | $\frac{1}{2}$ |
| $1\frac{3}{4}$ | $2\frac{1}{8}$ | $\frac{7}{16}$ | $\frac{7}{8}$ | $\frac{13}{16}$ | $2\frac{1}{8}$ | $\frac{3}{16}$ | $\frac{1}{4}$ | $2\frac{1}{8}$ | $\frac{1}{2}$ |
| $1\frac{7}{8}$ | $2\frac{1}{4}$ | $\frac{1}{2}$ | 1 | $\frac{13}{16}$ | $2\frac{1}{4}$ | $\frac{3}{16}$ | $\frac{1}{4}$ | $2\frac{1}{4}$ | $\frac{1}{2}$ |
| 2 | $2\frac{3}{8}$ | $\frac{1}{2}$ | 1 | $\frac{7}{8}$ | $2\frac{3}{8}$ | $\frac{3}{16}$ | $\frac{1}{4}$ | $2\frac{7}{16}$ | $\frac{9}{16}$ |
| $2\frac{1}{4}$ | $2\frac{11}{16}$ | $\frac{9}{16}$ | $1\frac{1}{8}$ | $\frac{15}{16}$ | $2\frac{11}{16}$ | $\frac{7}{32}$ | $\frac{9}{32}$ | $2\frac{3}{4}$ | $\frac{5}{8}$ |
| $2\frac{1}{2}$ | $2\frac{15}{16}$ | $\frac{5}{8}$ | $1\frac{1}{4}$ | 1 | $2\frac{15}{16}$ | $\frac{7}{32}$ | $\frac{5}{16}$ | 3 | $\frac{5}{8}$ |
| $2\frac{3}{4}$ | $3\frac{1}{4}$ | $\frac{11}{16}$ | $1\frac{3}{8}$ | $1\frac{1}{16}$ | $3\frac{1}{4}$ | $\frac{1}{4}$ | $\frac{11}{32}$ | $3\frac{3}{8}$ | $\frac{3}{4}$ |
| 3 | $3\frac{1}{2}$ | $\frac{3}{4}$ | $1\frac{1}{2}$ | $1\frac{1}{8}$ | $3\frac{1}{2}$ | $\frac{1}{4}$ | $\frac{3}{8}$ | $3\frac{5}{8}$ | $\frac{3}{4}$ |

## Eye Bolts for Flanges




| Bar | | Screw | | Head | | | | Casting | | | | | Over All M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Diam. A | Area | Root of Thread B | Area | C | D | E | F | G | H | I | K | L | |
| $\frac{1}{2}$ | .196 | .400 | .126 | $\frac{9}{16}$ | 1 | $\frac{7}{32}$ | $\frac{5}{8}$ | $\frac{11}{16}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{5}{8}$ | $\frac{5}{8}$ | $1\frac{11}{16}$ |
| $\frac{5}{8}$ | .307 | .507 | .202 | $\frac{11}{16}$ | $1\frac{5}{16}$ | $\frac{5}{16}$ | $\frac{3}{4}$ | $\frac{13}{16}$ | $\frac{9}{16}$ | $\frac{11}{16}$ | $\frac{13}{16}$ | $\frac{3}{4}$ | $1\frac{15}{16}$ |
| $\frac{3}{4}$ | .442 | .620 | .302 | $\frac{13}{16}$ | $1\frac{9}{16}$ | $\frac{3}{8}$ | $\frac{15}{16}$ | 1 | $\frac{5}{8}$ | $\frac{13}{16}$ | $\frac{15}{16}$ | $\frac{15}{16}$ | $2\frac{1}{4}$ |
| $\frac{7}{8}$ | .601 | .731 | .419 | $\frac{7}{8}$ | $1\frac{3}{4}$ | $\frac{7}{16}$ | $1\frac{1}{8}$ | $1\frac{3}{16}$ | $\frac{11}{16}$ | $\frac{15}{16}$ | $1\frac{1}{16}$ | $1\frac{1}{16}$ | $2\frac{9}{16}$ |
| 1 | .785 | .838 | .551 | 1 | 2 | $\frac{1}{2}$ | $1\frac{1}{4}$ | $1\frac{3}{8}$ | $\frac{3}{4}$ | $1\frac{1}{16}$ | $1\frac{1}{4}$ | $1\frac{3}{16}$ | $2\frac{7}{8}$ |
| $1\frac{1}{8}$ | .994 | .939 | .693 | $1\frac{1}{8}$ | $2\frac{1}{4}$ | $\frac{9}{16}$ | $1\frac{3}{8}$ | $1\frac{1}{2}$ | $\frac{13}{16}$ | $1\frac{3}{16}$ | $1\frac{7}{16}$ | $1\frac{5}{16}$ | $3\frac{1}{8}$ |
| $1\frac{1}{4}$ | 1.227 | 1.064 | .890 | $1\frac{1}{4}$ | $2\frac{5}{8}$ | $\frac{11}{16}$ | $1\frac{1}{2}$ | $1\frac{5}{8}$ | $\frac{7}{8}$ | $1\frac{5}{16}$ | $1\frac{9}{16}$ | $1\frac{7}{16}$ | $3\frac{3}{8}$ |
| $1\frac{3}{8}$ | 1.485 | 1.158 | 1.054 | $1\frac{3}{8}$ | $2\frac{7}{8}$ | $\frac{3}{4}$ | $1\frac{11}{16}$ | $1\frac{13}{16}$ | $\frac{15}{16}$ | $1\frac{7}{16}$ | $1\frac{3}{4}$ | $1\frac{9}{16}$ | $3\frac{11}{16}$ |
| $1\frac{1}{2}$ | 1.767 | 1.283 | 1.294 | $1\frac{1}{2}$ | $3\frac{1}{8}$ | $\frac{13}{16}$ | $1\frac{13}{16}$ | $1\frac{15}{16}$ | 1 | $1\frac{5}{8}$ | $1\frac{7}{8}$ | $1\frac{11}{16}$ | $3\frac{15}{16}$ |
| $1\frac{5}{8}$ | 2.074 | 1.389 | 1.515 | $1\frac{5}{8}$ | $3\frac{3}{8}$ | $\frac{7}{8}$ | $1\frac{15}{16}$ | $2\frac{1}{16}$ | $1\frac{1}{16}$ | $1\frac{3}{4}$ | 2 | $1\frac{7}{8}$ | $4\frac{3}{16}$ |
| $1\frac{3}{4}$ | 2.405 | 1.490 | 1.744 | $1\frac{3}{4}$ | $3\frac{5}{8}$ | $\frac{15}{16}$ | $2\frac{1}{8}$ | $2\frac{1}{4}$ | $1\frac{1}{8}$ | $1\frac{13}{16}$ | $2\frac{3}{16}$ | 2 | $4\frac{1}{2}$ |
| $1\frac{7}{8}$ | 2.761 | 1.615 | 2.049 | $1\frac{7}{8}$ | $3\frac{7}{8}$ | 1 | $2\frac{1}{4}$ | $2\frac{3}{8}$ | $1\frac{3}{16}$ | 2 | $2\frac{3}{8}$ | $2\frac{1}{8}$ | $4\frac{3}{4}$ |
| 2 | 3.142 | 1.711 | 2.300 | 2 | $4\frac{1}{8}$ | $1\frac{1}{16}$ | $2\frac{3}{8}$ | $2\frac{1}{2}$ | $1\frac{1}{4}$ | $2\frac{1}{8}$ | $2\frac{1}{2}$ | $2\frac{1}{4}$ | 5 |

## Bolt Ends with Slot and Cotter

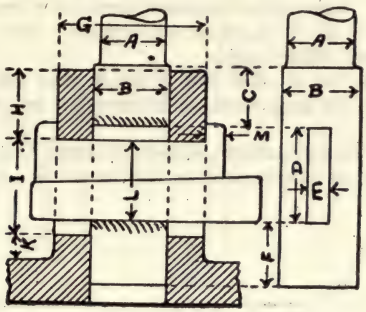



Rigid Connection

| Bar | | Collar | | Shank | | | | Slot | | Cast Boss | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Diam. A | Area | Dia. B | Thickness C | Dia. D | Length E | Length F | Length G | Width H | Depth F | Dia. K | Length L | Length M | Length N |
| 1 | .785 | $1\frac{7}{8}$ | $\frac{13}{16}$ | $1\frac{1}{8}$ | $\frac{7}{8}$ | $1\frac{1}{2}$ | 1 | $\frac{5}{16}$ | $1\frac{1}{4}$ | $2\frac{1}{4}$ | $1\frac{1}{8}$ | $1\frac{1}{2}$ | $\frac{3}{8}$ |
| $1\frac{1}{8}$ | .994 | $2\frac{1}{8}$ | $\frac{7}{8}$ | $1\frac{1}{4}$ | 1 | $1\frac{11}{16}$ | $1\frac{1}{8}$ | $\frac{5}{16}$ | $1\frac{3}{8}$ | $2\frac{1}{2}$ | $1\frac{1}{4}$ | $1\frac{11}{16}$ | $\frac{3}{8}$ |
| $1\frac{1}{4}$ | 1.227 | $2\frac{1}{4}$ | 1 | $1\frac{3}{8}$ | $1\frac{1}{8}$ | $1\frac{7}{8}$ | $1\frac{1}{4}$ | $\frac{3}{8}$ | $1\frac{9}{16}$ | $2\frac{7}{8}$ | $1\frac{7}{16}$ | $1\frac{13}{16}$ | $\frac{7}{16}$ |
| $1\frac{3}{8}$ | 1.485 | $2\frac{1}{2}$ | $1\frac{1}{8}$ | $1\frac{1}{2}$ | $1\frac{1}{4}$ | $2\frac{1}{16}$ | $1\frac{3}{8}$ | $\frac{3}{8}$ | $1\frac{11}{16}$ | $3\frac{1}{8}$ | $1\frac{9}{16}$ | 2 | $\frac{1}{2}$ |
| $1\frac{1}{2}$ | 1.767 | $2\frac{3}{4}$ | $1\frac{3}{16}$ | $1\frac{11}{16}$ | $1\frac{5}{16}$ | $2\frac{1}{4}$ | $1\frac{1}{2}$ | $\frac{7}{16}$ | $1\frac{7}{8}$ | $3\frac{5}{8}$ | $1\frac{13}{16}$ | $2\frac{1}{8}$ | $\frac{1}{2}$ |
| $1\frac{5}{8}$ | 2.074 | $2\frac{7}{8}$ | $1\frac{1}{4}$ | $1\frac{13}{16}$ | $1\frac{7}{16}$ | $2\frac{7}{16}$ | $1\frac{5}{8}$ | $\frac{7}{16}$ | 2 | $3\frac{3}{4}$ | $1\frac{7}{8}$ | $2\frac{5}{16}$ | $\frac{9}{16}$ |
| $1\frac{3}{4}$ | 2.405 | $3\frac{1}{8}$ | $1\frac{3}{8}$ | $1\frac{15}{16}$ | $1\frac{9}{16}$ | $2\frac{5}{8}$ | $1\frac{3}{4}$ | $\frac{1}{2}$ | $2\frac{3}{16}$ | 4 | 2 | $2\frac{7}{16}$ | $\frac{9}{16}$ |
| $1\frac{7}{8}$ | 2.761 | $3\frac{3}{8}$ | $1\frac{7}{16}$ | $2\frac{1}{16}$ | $1\frac{11}{16}$ | $2\frac{13}{16}$ | $1\frac{7}{8}$ | $\frac{1}{2}$ | $2\frac{5}{16}$ | $4\frac{1}{4}$ | $2\frac{1}{8}$ | $2\frac{5}{8}$ | $\frac{9}{16}$ |
| 2 | 3.142 | $3\frac{1}{2}$ | $1\frac{9}{16}$ | $2\frac{1}{4}$ | $1\frac{3}{4}$ | 3 | 2 | $\frac{9}{16}$ | $2\frac{1}{2}$ | $4\frac{1}{2}$ | $2\frac{1}{4}$ | $2\frac{3}{4}$ | $\frac{5}{8}$ |
| $2\frac{1}{4}$ | 3.976 | 4 | $1\frac{3}{4}$ | $2\frac{1}{2}$ | 2 | $3\frac{3}{8}$ | $2\frac{1}{4}$ | $\frac{5}{8}$ | $2\frac{13}{16}$ | $5\frac{1}{8}$ | $2\frac{9}{16}$ | $3\frac{1}{16}$ | $\frac{11}{16}$ |
| $2\frac{1}{2}$ | 4.909 | $4\frac{3}{8}$ | $1\frac{7}{8}$ | $2\frac{3}{4}$ | $2\frac{3}{16}$ | $3\frac{3}{4}$ | $2\frac{1}{2}$ | $\frac{11}{16}$ | $3\frac{1}{8}$ | $5\frac{5}{8}$ | $2\frac{13}{16}$ | $3\frac{3}{8}$ | $\frac{11}{16}$ |
| $2\frac{3}{4}$ | 5.940 | $4\frac{7}{8}$ | $2\frac{1}{8}$ | $3\frac{1}{16}$ | $2\frac{7}{16}$ | $4\frac{1}{8}$ | $2\frac{3}{4}$ | $\frac{3}{4}$ | $3\frac{7}{16}$ | $6\frac{1}{4}$ | $3\frac{1}{8}$ | $3\frac{11}{16}$ | $\frac{3}{4}$ |
| 3 | 7.069 | $5\frac{1}{4}$ | $2\frac{1}{4}$ | $3\frac{5}{16}$ | $2\frac{5}{8}$ | $4\frac{1}{2}$ | 3 | $\frac{13}{16}$ | $3\frac{3}{4}$ | $6\frac{3}{4}$ | $3\frac{3}{8}$ | 4 | $\frac{13}{16}$ |
| $3\frac{1}{4}$ | 8.296 | $5\frac{3}{4}$ | $2\frac{1}{2}$ | $3\frac{5}{8}$ | $2\frac{7}{8}$ | $4\frac{7}{8}$ | $3\frac{1}{4}$ | $\frac{13}{16}$ | $4\frac{1}{16}$ | $7\frac{1}{4}$ | $3\frac{5}{8}$ | $4\frac{5}{16}$ | $\frac{7}{8}$ |
| $3\frac{1}{2}$ | 9.621 | $6\frac{1}{8}$ | $2\frac{5}{8}$ | $3\frac{7}{8}$ | 3 | $5\frac{1}{4}$ | $3\frac{1}{2}$ | $\frac{7}{8}$ | $4\frac{3}{8}$ | $7\frac{7}{8}$ | $3\frac{15}{16}$ | $4\frac{5}{8}$ | $\frac{15}{16}$ |
| $3\frac{3}{4}$ | 11.05 | $6\frac{1}{2}$ | $2\frac{7}{8}$ | $4\frac{1}{4}$ | $3\frac{1}{4}$ | $5\frac{5}{8}$ | $3\frac{3}{4}$ | $\frac{15}{16}$ | $4\frac{11}{16}$ | $8\frac{3}{8}$ | $4\frac{3}{16}$ | $4\frac{15}{16}$ | 1 |
| 4 | 12.57 | 7 | 3 | $4\frac{1}{2}$ | $3\frac{1}{2}$ | 6 | 4 | 1 | 5 | 9 | $4\frac{1}{2}$ | $5\frac{1}{4}$ | 1 |

Proportions in this table are based on diameter of bar A and corresponding upset screw ends, for which see special table.

BOLT ENDS WITH SLOT GIB AND KEY FOR RESISTING TENSION ONLY




| Bar Diam. A | Bar Area | Diam. B | C | D | E | F | G | H | I | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .785 | $1\frac{1}{8}$ | 1 | $1\frac{1}{2}$ | $\frac{5}{16}$ | 1 | $2\frac{1}{4}$ | $1\frac{1}{8}$ | $1\frac{1}{2}$ | $\frac{3}{8}$ | $1\frac{1}{4}$ | $\frac{1}{4}$ |
| $1\frac{1}{8}$ | .994 | $1\frac{1}{4}$ | $1\frac{1}{8}$ | $1\frac{11}{16}$ | $\frac{5}{16}$ | $1\frac{1}{8}$ | $2\frac{1}{2}$ | $1\frac{1}{4}$ | $1\frac{11}{16}$ | $\frac{7}{16}$ | $1\frac{3}{8}$ | $\frac{1}{4}$ |
| $1\frac{1}{4}$ | 1.227 | $1\frac{3}{8}$ | $1\frac{1}{4}$ | $1\frac{7}{8}$ | $\frac{3}{8}$ | $1\frac{1}{4}$ | $2\frac{7}{8}$ | $1\frac{3}{8}$ | $1\frac{7}{8}$ | $\frac{1}{2}$ | $1\frac{7}{16}$ | $\frac{1}{4}$ |
| $1\frac{3}{8}$ | 1.485 | $1\frac{1}{2}$ | $1\frac{3}{8}$ | $2\frac{1}{16}$ | $\frac{3}{8}$ | $1\frac{3}{8}$ | $3\frac{1}{8}$ | $1\frac{1}{2}$ | $2\frac{1}{16}$ | $\frac{1}{2}$ | $1\frac{11}{16}$ | $\frac{5}{16}$ |
| $1\frac{1}{2}$ | 1.767 | $1\frac{11}{16}$ | $1\frac{1}{2}$ | $2\frac{1}{4}$ | $\frac{7}{16}$ | $1\frac{1}{2}$ | $3\frac{5}{8}$ | $1\frac{11}{16}$ | $2\frac{1}{4}$ | $\frac{9}{16}$ | $1\frac{7}{8}$ | $\frac{5}{16}$ |
| $1\frac{5}{8}$ | 2.074 | $1\frac{13}{16}$ | $1\frac{5}{8}$ | $2\frac{7}{16}$ | $\frac{7}{16}$ | $1\frac{5}{8}$ | $3\frac{3}{4}$ | $1\frac{13}{16}$ | $2\frac{7}{16}$ | $\frac{5}{8}$ | 2 | $\frac{3}{8}$ |
| $1\frac{3}{4}$ | 2.405 | $1\frac{15}{16}$ | $1\frac{3}{4}$ | $2\frac{5}{8}$ | $\frac{1}{2}$ | $1\frac{3}{4}$ | 4 | $1\frac{15}{16}$ | $2\frac{5}{8}$ | $\frac{11}{16}$ | $2\frac{3}{16}$ | $\frac{3}{8}$ |
| $1\frac{7}{8}$ | 2.761 | $2\frac{1}{16}$ | $1\frac{7}{8}$ | $2\frac{13}{16}$ | $\frac{1}{2}$ | $1\frac{7}{8}$ | $4\frac{1}{4}$ | $2\frac{1}{16}$ | $2\frac{13}{16}$ | $\frac{11}{16}$ | $2\frac{5}{16}$ | $\frac{3}{8}$ |
| 2 | 3.142 | $2\frac{1}{4}$ | 2 | 3 | $\frac{9}{16}$ | 2 | $4\frac{1}{2}$ | $2\frac{1}{4}$ | 3 | $\frac{3}{4}$ | $2\frac{1}{2}$ | $\frac{7}{16}$ |
| $2\frac{1}{4}$ | 3.976 | $2\frac{1}{2}$ | $2\frac{1}{4}$ | $3\frac{3}{8}$ | $\frac{5}{8}$ | $2\frac{1}{4}$ | $5\frac{1}{8}$ | $2\frac{1}{2}$ | $3\frac{3}{8}$ | $\frac{7}{8}$ | $2\frac{13}{16}$ | $\frac{7}{16}$ |
| $2\frac{1}{2}$ | 4.909 | $2\frac{3}{4}$ | $2\frac{1}{2}$ | $3\frac{3}{4}$ | $\frac{11}{16}$ | $2\frac{1}{2}$ | $5\frac{5}{8}$ | $2\frac{3}{4}$ | $3\frac{3}{4}$ | $\frac{15}{16}$ | $3\frac{1}{8}$ | $\frac{1}{2}$ |
| $2\frac{3}{4}$ | 5.940 | $3\frac{1}{16}$ | $2\frac{3}{4}$ | $4\frac{1}{8}$ | $\frac{3}{4}$ | $2\frac{3}{4}$ | $6\frac{1}{4}$ | $3\frac{1}{16}$ | $4\frac{1}{8}$ | 1 | $3\frac{7}{16}$ | $\frac{1}{2}$ |
| 3 | 7.069 | $3\frac{5}{16}$ | 3 | $4\frac{1}{2}$ | $\frac{13}{16}$ | 3 | $6\frac{3}{4}$ | $3\frac{5}{16}$ | $4\frac{1}{2}$ | $1\frac{1}{8}$ | $3\frac{3}{4}$ | $\frac{9}{16}$ |
| $3\frac{1}{4}$ | 8.296 | $3\frac{5}{8}$ | $3\frac{1}{4}$ | $4\frac{7}{8}$ | $\frac{13}{16}$ | $3\frac{1}{4}$ | $7\frac{1}{4}$ | $3\frac{5}{8}$ | $4\frac{7}{8}$ | $1\frac{1}{4}$ | $4\frac{1}{16}$ | $\frac{5}{8}$ |
| $3\frac{1}{2}$ | 9.621 | $3\frac{7}{8}$ | $3\frac{1}{2}$ | $5\frac{1}{4}$ | $\frac{7}{8}$ | $3\frac{1}{2}$ | $7\frac{7}{8}$ | $3\frac{7}{8}$ | $5\frac{1}{4}$ | $1\frac{5}{16}$ | $4\frac{3}{8}$ | $\frac{11}{16}$ |
| $3\frac{3}{4}$ | 11.05 | $4\frac{1}{4}$ | $3\frac{3}{4}$ | $5\frac{5}{8}$ | $\frac{15}{16}$ | $3\frac{3}{4}$ | $8\frac{3}{8}$ | $4\frac{1}{4}$ | $5\frac{5}{8}$ | $1\frac{7}{16}$ | $4\frac{11}{16}$ | $\frac{11}{16}$ |
| 4 | 12.57 | $4\frac{1}{2}$ | 4 | 6 | 1 | 4 | 9 | $4\frac{1}{2}$ | 6 | $1\frac{1}{2}$ | 5 | $\frac{3}{4}$ |

## WRENCHES

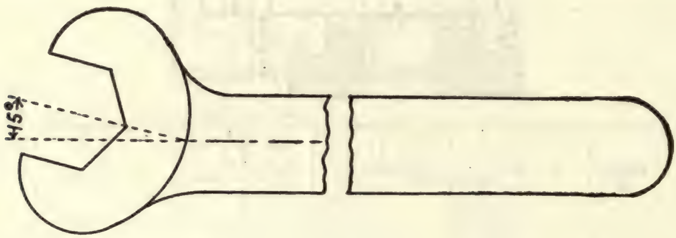
The open-end wrench sketched for accompanying table of dimensions has the long diameter of nut in line with the center of the handle; this is a common but not universal practice. To meet service requirements, open-end wrenches are made with the center line of opening ranging from 15° to 45°, as shown in the accompanying sketches; whatever the angle, the proportions for the head are not changed.

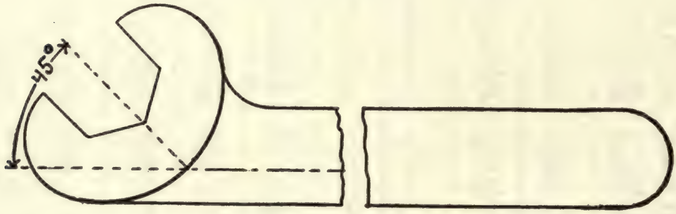
An open-end wrench, with head at 45°, is frequently used in place of a hammer during erecting operations, thereby subjecting it to distortion or breakage. The ordinary proportions are such that the little surplus strength a wrench may have is quickly dissipated by usage wholly foreign to its design. A wrench to withstand such service must be more liberal in its dimensions than indicated in the table, and should be specially forged. Reference may be here made to those special wrenches (sometimes called flogging wrenches) that are employed in setting with a sledge such nuts as cannot be properly tightened by means of a standard wrench. In general, such wrenches have the same dimensions as given in the table for open-end wrenches, excepting only that no

reduction is made in the thickness of handle; that is, thickness of head C continues and takes the place of G. This added thickness presents a larger surface for the face of the sledge when driving a nut to its final adjustment. The handle is always short, seldom more than half the tabular length.

A wrench with an opening at each end is much used, especially for medium and small bolts and nuts, but for large work such wrenches are too heavy and otherwise inconvenient.

For extra heavy work box wrenches are best; a sketch and table of proportions are given. The eye at the end of handle provides for the use of a rope enabling several men

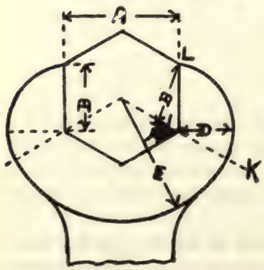



to assist by pulling, or for the insertion of a tackle hook, if unusual tension is required.

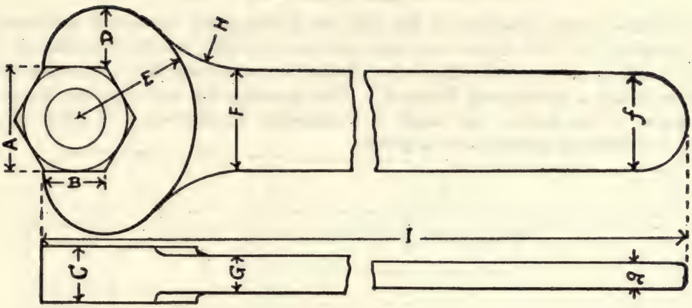
Framed structures requiring dimensioned timber in the larger sizes, such as commonly used in the construction of bridges, trestles, framed roofs of wide span, seldom have other than square nuts; an efficient wrench, easily forged in the field, is shown in accompanying sketch together with table of working dimensions.

## PROPORTIONING A WRENCH FOR A HEXAGON NUT




Describe a hexagon corresponding in size to that of the nut, A being its short diameter. Draw a line K, from the center through one corner of hexagon. With the corner L as a center and B as a radius, describe a short arc inside the hexagon. Lay off the width D (in the accompanying table D approximates 0.5 A), and with B as a radius, describe a short arc inside the hexagon intersecting the first one at M. With M as a center and B as a radius, describe the outer curve of the jaw to the line K; the distance from this intersection to center of hexagon is the radius E for the lower connecting curve.

## Wrenches

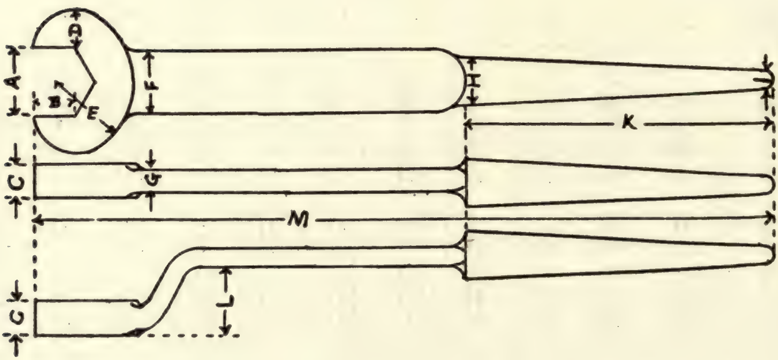



| Diameter Bolt | A | B | C | D | E | F | f | G | g | H | I |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1/4 | 1/2 | 1/4 | 1/4 | 1/4 | 17/32 | 1/2 | 1/2 | 3/16 | 1/8 | 1/4 | 4 |
| 5/16 | 19/32 | 5/16 | 1/4 | 9/32 | 19/32 | 9/16 | 9/16 | 7/32 | 1/8 | 5/16 | 5 |
| 3/8 | 11/16 | 3/8 | 5/16 | 11/32 | 3/4 | 5/8 | 5/8 | 1/4 | 5/32 | 3/8 | 6 |
| 7/16 | 25/32 | 7/16 | 3/8 | 3/8 | 13/16 | 11/16 | 11/16 | 9/32 | 5/32 | 7/16 | 7 |
| 1/2 | 7/8 | 1/2 | 7/16 | 7/16 | 15/16 | 3/4 | 3/4 | 5/16 | 3/16 | 1/2 | 8 |
| 9/16 | 31/32 | 9/16 | 1/2 | 1/2 | 1 1/16 | 13/16 | 13/16 | 11/32 | 3/16 | 9/16 | 9 |
| 5/8 | 1 1/16 | 5/8 | 9/16 | 17/32 | 1 5/32 | 15/16 | 13/16 | 11/32 | 7/32 | 5/8 | 10 |
| 3/4 | 1 1/4 | 3/4 | 5/8 | 5/8 | 1 5/16 | 1 1/8 | 7/8 | 3/8 | 1/4 | 3/4 | 11 1/2 |
| 7/8 | 1 7/16 | 13/16 | 11/16 | 23/32 | 1 9/16 | 1 5/16 | 15/16 | 7/16 | 9/32 | 7/8 | 13 1/4 |
| 1 | 1 5/8 | 15/16 | 13/16 | 13/16 | 1 3/4 | 1 1/2 | 1 | 7/16 | 5/16 | 1 | 15 |
| 1 1/8 | 1 13/16 | 1 1/16 | 7/8 | 29/32 | 1 15/16 | 1 5/8 | 1 | 7/16 | 5/16 | 1 1/8 | 17 |
| 1 1/4 | 2 | 1 1/8 | 15/16 | 1 | 2 5/32 | 1 13/16 | 1 1/16 | 15/32 | 5/16 | 1 1/4 | 19 |
| 1 3/8 | 2 3/16 | 1 1/4 | 1 | 1 1/16 | 2 3/8 | 1 15/16 | 1 1/8 | 1/2 | 11/32 | 1 3/8 | 21 |
| 1 1/2 | 2 3/8 | 1 3/8 | 1 1/16 | 1 3/16 | 2 9/16 | 2 1/8 | 1 1/8 | 17/32 | 11/32 | 1 1/2 | 22 1/2 |
| 1 5/8 | 2 9/16 | 1 1/2 | 1 3/16 | 1 1/4 | 2 3/4 | 2 1/4 | 1 3/16 | 9/16 | 11/32 | 1 5/8 | 24 |
| 1 3/4 | 2 3/4 | 1 9/16 | 1 1/4 | 1 3/8 | 3 | 2 7/16 | 1 1/4 | 9/16 | 3/8 | 1 3/4 | 26 |
| 1 7/8 | 2 15/16 | 1 11/16 | 1 5/16 | 1 7/16 | 3 1/8 | 2 9/16 | 1 5/16 | 19/32 | 3/8 | 1 7/8 | 28 |
| 2 | 3 1/8 | 1 13/16 | 1 3/8 | 1 9/16 | 3 3/8 | 2 3/4 | 1 3/8 | 5/8 | 3/8 | 2 | 30 |
| 2 1/4 | 3 1/2 | 2 | 1 1/2 | 1 3/4 | 3 3/4 | 2 7/8 | 1 7/16 | 21/32 | 3/8 | 2 1/8 | 32 |
| 2 1/2 | 3 7/8 | 2 1/4 | 1 5/8 | 1 15/16 | 4 3/16 | 3 | 1 1/2 | 23/32 | 13/32 | 2 1/4 | 34 1/2 |
| 2 3/4 | 4 1/4 | 2 7/16 | 1 13/16 | 2 1/8 | 4 9/16 | 3 3/16 | 1 9/16 | 3/4 | 13/32 | 2 3/8 | 36 3/4 |
| 3 | 4 5/8 | 2 5/8 | 1 15/16 | 2 1/4 | 4 15/16 | 3 3/8 | 1 11/16 | 13/16 | 7/16 | 2 1/2 | 39 |
| 3 1/4 | 5 | 2 7/8 | 2 | 2 7/16 | 5 3/8 | 3 1/2 | 1 3/4 | 27/32 | 7/16 | 2 5/8 | 41 |
| 3 1/2 | 5 3/8 | 3 1/16 | 2 1/4 | 2 5/8 | 5 3/4 | 3 11/16 | 1 13/16 | 29/32 | 15/32 | 2 3/4 | 43 1/2 |
| 3 3/4 | 5 3/4 | 3 5/16 | 2 3/8 | 2 7/8 | 6 3/16 | 3 13/16 | 1 7/8 | 31/32 | 15/32 | 2 7/8 | 45 3/4 |
| 4 | 6 1/8 | 3 1/2 | 2 1/2 | 3 | 6 9/16 | 4 | 2 | 1 | 1/2 | 3 | 48 |

## Wrenches for Structural Work

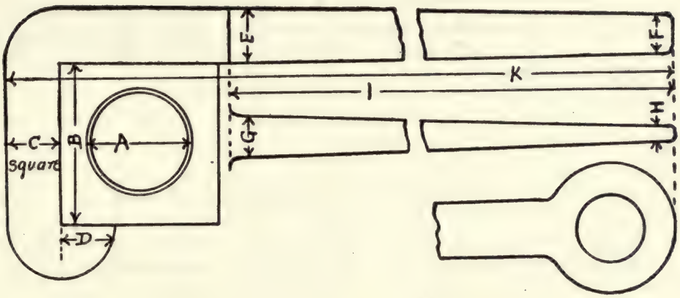
For structural work, whether in the mill or in the field, open-end wrenches with a tang for bringing the bolt holes into line are used to the practical exclusion of every other kind. When the wrench is flat it is called a Construction Wrench; when the handle is offset it is called a Structural Wrench. The opening for nut may be either straight or at an angle; if the latter, the angle is commonly 15 degrees. A table of working dimensions for sizes in general use is given.

### Wrenches for Structural Work




| Dia. Bolt | A | B | C | D | E | F | G | H | I | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\frac{1}{2}$ | $\frac{7}{8}$ | $\frac{1}{2}$ | $\frac{7}{16}$ | $\frac{7}{16}$ | $\frac{15}{16}$ | $\frac{7}{8}$ | $\frac{5}{16}$ | $\frac{3}{4}$ | $\frac{1}{4}$ | 4 | 1 | 12 |
| $\frac{5}{8}$ | $1\frac{1}{16}$ | $\frac{5}{8}$ | $\frac{9}{16}$ | $\frac{9}{16}$ | $1\frac{3}{16}$ | 1 | $\frac{3}{8}$ | $\frac{7}{8}$ | $\frac{1}{4}$ | $4\frac{1}{2}$ | $1\frac{1}{8}$ | 14 |
| $\frac{3}{4}$ | $1\frac{1}{4}$ | $\frac{23}{32}$ | $\frac{5}{8}$ | $\frac{5}{8}$ | $1\frac{11}{32}$ | $1\frac{1}{8}$ | $\frac{3}{8}$ | 1 | $\frac{3}{8}$ | 5 | $1\frac{1}{4}$ | 15 |
| $\frac{7}{8}$ | $1\frac{7}{16}$ | $\frac{27}{32}$ | $\frac{3}{4}$ | $\frac{3}{4}$ | $1\frac{9}{16}$ | $1\frac{1}{4}$ | $\frac{7}{16}$ | $1\frac{1}{8}$ | $\frac{3}{8}$ | $5\frac{1}{2}$ | $1\frac{3}{8}$ | 16 |
| 1 | $1\frac{5}{8}$ | $\frac{15}{16}$ | $\frac{7}{8}$ | $\frac{13}{16}$ | $1\frac{3}{4}$ | $1\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | $\frac{1}{2}$ | 6 | $1\frac{3}{8}$ | 18 |
| $1\frac{1}{8}$ | $1\frac{13}{16}$ | $1\frac{1}{16}$ | 1 | $\frac{7}{8}$ | $1\frac{15}{16}$ | $1\frac{5}{8}$ | $\frac{1}{2}$ | $1\frac{3}{8}$ | $\frac{1}{2}$ | $6\frac{1}{2}$ | $1\frac{1}{2}$ | 20 |
| $1\frac{1}{4}$ | 2 | $1\frac{5}{32}$ | $1\frac{1}{8}$ | 1 | $2\frac{3}{16}$ | $1\frac{3}{4}$ | $\frac{9}{16}$ | $1\frac{1}{2}$ | $\frac{1}{2}$ | 7 | $1\frac{5}{8}$ | 22 |

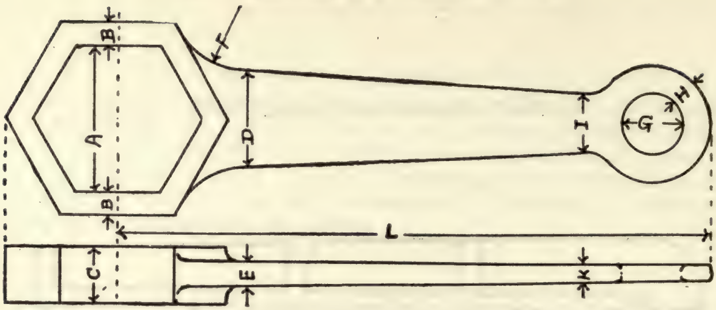
## Field Wrench for Square Nuts




### For United States Standard Nuts

| Bolt Diam. A | Side of Nut B | C | D | E | F | G | H | K |
|---|---|---|---|---|---|---|---|---|
| 1 | $1\frac{5}{8}$ | $\frac{13}{16}$ | $\frac{3}{8}$ | $\frac{13}{16}$ | 1 | $\frac{13}{16}$ | $\frac{5}{16}$ | 15 |
| $1\frac{1}{8}$ | $1\frac{13}{16}$ | $\frac{7}{8}$ | $\frac{3}{8}$ | $\frac{7}{8}$ | 1 | $\frac{7}{8}$ | $\frac{5}{16}$ | 17 |
| $1\frac{1}{4}$ | 2 | 1 | $\frac{3}{8}$ | 1 | 1 | 1 | $\frac{5}{16}$ | 19 |
| $1\frac{3}{8}$ | $2\frac{3}{16}$ | $1\frac{1}{8}$ | $\frac{1}{2}$ | $1\frac{1}{8}$ | $1\frac{1}{8}$ | 1 | $\frac{5}{16}$ | 21 |
| $1\frac{1}{2}$ | $2\frac{3}{8}$ | $1\frac{1}{4}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | $1\frac{1}{8}$ | 1 | $\frac{3}{8}$ | 22 |
| $1\frac{5}{8}$ | $2\frac{9}{16}$ | $1\frac{1}{4}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | $1\frac{1}{8}$ | 1 | $\frac{3}{8}$ | 24 |
| $1\frac{3}{4}$ | $2\frac{3}{4}$ | $1\frac{3}{8}$ | $\frac{5}{8}$ | $1\frac{3}{8}$ | $1\frac{1}{4}$ | $1\frac{1}{8}$ | $\frac{3}{8}$ | 26 |
| $1\frac{7}{8}$ | $2\frac{15}{16}$ | $1\frac{3}{8}$ | $\frac{5}{8}$ | $1\frac{3}{8}$ | $1\frac{1}{4}$ | $1\frac{1}{8}$ | $\frac{3}{8}$ | 28 |
| 2 | $3\frac{1}{8}$ | $1\frac{1}{2}$ | $\frac{5}{8}$ | $1\frac{1}{2}$ | $1\frac{3}{8}$ | $1\frac{1}{4}$ | $\frac{3}{8}$ | 30 |
| $2\frac{1}{4}$ | $3\frac{1}{2}$ | $1\frac{1}{2}$ | $\frac{3}{4}$ | $1\frac{1}{2}$ | $1\frac{3}{8}$ | $1\frac{1}{4}$ | $\frac{3}{8}$ | 32 |
| $2\frac{1}{2}$ | $3\frac{7}{8}$ | 2 | $\frac{3}{4}$ | 2 | $1\frac{1}{2}$ | $1\frac{1}{2}$ | $\frac{3}{8}$ | 34 |
| $2\frac{3}{4}$ | $4\frac{1}{4}$ | 2 | $\frac{7}{8}$ | 2 | $1\frac{1}{2}$ | $1\frac{1}{2}$ | $\frac{3}{8}$ | 36 |
| 3 | $4\frac{5}{8}$ | 2 | 1 | 2 | $1\frac{5}{8}$ | $1\frac{1}{2}$ | $\frac{3}{8}$ | 39 |

## Box Wrenches for Hexagon Nuts




| Diam. Bolt | A | B | C | D | E | F | G | H | I | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | $1\frac{5}{8}$ | $\frac{1}{4}$ | $\frac{3}{4}$ | $1\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{5}{8}$ | .. | .. | 1 | $\frac{3}{8}$ | 15 |
| $1\frac{1}{8}$ | $1\frac{13}{16}$ | $\frac{5}{16}$ | $\frac{3}{4}$ | $1\frac{5}{8}$ | $\frac{1}{2}$ | $\frac{3}{4}$ | .. | .. | 1 | $\frac{7}{16}$ | 16 |
| $1\frac{1}{4}$ | 2 | $\frac{3}{8}$ | $\frac{7}{8}$ | $1\frac{3}{4}$ | $\frac{9}{16}$ | $\frac{7}{8}$ | .. | .. | $1\frac{1}{8}$ | $\frac{7}{16}$ | 18 |
| $1\frac{3}{8}$ | $2\frac{3}{16}$ | $\frac{3}{8}$ | $\frac{7}{8}$ | $1\frac{7}{8}$ | $\frac{9}{16}$ | 1 | .. | .. | $1\frac{1}{8}$ | $\frac{7}{16}$ | 20 |
| $1\frac{1}{2}$ | $2\frac{3}{8}$ | $\frac{3}{8}$ | 1 | 2 | $\frac{9}{16}$ | $1\frac{1}{8}$ | .. | .. | $1\frac{1}{8}$ | $\frac{1}{2}$ | 22 |
| $1\frac{5}{8}$ | $2\frac{9}{16}$ | $\frac{7}{16}$ | 1 | $2\frac{1}{8}$ | $\frac{5}{8}$ | $1\frac{5}{16}$ | .. | .. | $1\frac{1}{4}$ | $\frac{1}{2}$ | 24 |
| $1\frac{3}{4}$ | $2\frac{3}{4}$ | $\frac{7}{16}$ | $1\frac{1}{8}$ | $2\frac{1}{4}$ | $\frac{5}{8}$ | $1\frac{3}{8}$ | .. | .. | $1\frac{1}{4}$ | $\frac{1}{2}$ | 26 |
| $1\frac{7}{8}$ | $2\frac{15}{16}$ | $\frac{7}{16}$ | $1\frac{1}{8}$ | $2\frac{3}{8}$ | $\frac{5}{8}$ | $1\frac{1}{2}$ | .. | .. | $1\frac{3}{8}$ | $\frac{1}{2}$ | 28 |
| 2 | $3\frac{1}{8}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | $2\frac{1}{2}$ | $\frac{11}{16}$ | $1\frac{3}{4}$ | .. | .. | $1\frac{3}{8}$ | $\frac{9}{16}$ | 30 |
| $2\frac{1}{4}$ | $3\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{3}{8}$ | $2\frac{5}{8}$ | $\frac{11}{16}$ | $1\frac{7}{8}$ | .. | .. | $1\frac{1}{2}$ | $\frac{9}{16}$ | 33 |
| $2\frac{1}{2}$ | $3\frac{7}{8}$ | $\frac{1}{2}$ | $1\frac{1}{2}$ | $2\frac{7}{8}$ | $\frac{3}{4}$ | 2 | 2 | 1 | 2 | $\frac{9}{16}$ | 36 |
| $2\frac{3}{4}$ | $4\frac{1}{4}$ | $\frac{9}{16}$ | $1\frac{5}{8}$ | 3 | $\frac{13}{16}$ | $2\frac{1}{4}$ | 2 | 1 | 2 | $\frac{9}{16}$ | 38 |
| 3 | $4\frac{5}{8}$ | $\frac{9}{16}$ | $1\frac{3}{4}$ | $3\frac{1}{4}$ | $\frac{7}{8}$ | $2\frac{3}{8}$ | $2\frac{1}{4}$ | $1\frac{1}{8}$ | $2\frac{1}{4}$ | $\frac{5}{8}$ | 40 |
| $3\frac{1}{4}$ | 5 | $\frac{5}{8}$ | $1\frac{7}{8}$ | $3\frac{3}{8}$ | $\frac{7}{8}$ | $2\frac{5}{8}$ | $2\frac{1}{4}$ | $1\frac{1}{8}$ | $2\frac{1}{4}$ | $\frac{5}{8}$ | 42 |
| $3\frac{1}{2}$ | $5\frac{3}{8}$ | $\frac{11}{16}$ | 2 | $3\frac{5}{8}$ | $\frac{15}{16}$ | $2\frac{13}{16}$ | $2\frac{1}{4}$ | $1\frac{1}{8}$ | $2\frac{1}{4}$ | $\frac{5}{8}$ | 44 |
| $3\frac{3}{4}$ | $5\frac{3}{4}$ | $\frac{11}{16}$ | $2\frac{1}{8}$ | $3\frac{3}{4}$ | $\frac{15}{16}$ | 3 | $2\frac{1}{4}$ | $1\frac{1}{8}$ | $2\frac{1}{4}$ | $\frac{5}{8}$ | 46 |
| 4 | $6\frac{1}{8}$ | $\frac{3}{4}$ | $2\frac{1}{4}$ | 4 | 1 | $3\frac{1}{4}$ | $2\frac{1}{4}$ | $1\frac{1}{8}$ | $2\frac{1}{4}$ | $\frac{5}{8}$ | 48 |
| $4\frac{1}{4}$ | $6\frac{1}{2}$ | $\frac{3}{4}$ | $2\frac{3}{8}$ | $4\frac{1}{4}$ | 1 | $3\frac{3}{8}$ | $2\frac{1}{4}$ | $1\frac{1}{8}$ | $2\frac{1}{4}$ | $\frac{5}{8}$ | 51 |
| $4\frac{1}{2}$ | $6\frac{7}{8}$ | $\frac{13}{16}$ | $2\frac{1}{2}$ | $4\frac{3}{8}$ | 1 | $3\frac{5}{8}$ | $2\frac{1}{4}$ | $1\frac{1}{8}$ | $2\frac{1}{4}$ | $\frac{5}{8}$ | 54 |
| $4\frac{3}{4}$ | $7\frac{1}{4}$ | $\frac{13}{16}$ | $2\frac{5}{8}$ | $4\frac{1}{2}$ | 1 | $3\frac{7}{8}$ | $2\frac{1}{4}$ | $1\frac{1}{8}$ | $2\frac{1}{4}$ | $\frac{5}{8}$ | 57 |
| 5 | $7\frac{5}{8}$ | $\frac{7}{8}$ | $2\frac{3}{4}$ | $4\frac{5}{8}$ | 1 | $4\frac{1}{8}$ | $2\frac{1}{2}$ | $1\frac{1}{4}$ | $2\frac{1}{2}$ | $\frac{11}{16}$ | 60 |
| $5\frac{1}{4}$ | 8 | $\frac{7}{8}$ | $2\frac{3}{4}$ | $4\frac{3}{4}$ | 1 | $4\frac{1}{4}$ | $2\frac{1}{2}$ | $1\frac{1}{4}$ | $2\frac{1}{2}$ | $\frac{11}{16}$ | 63 |
| $5\frac{1}{2}$ | $8\frac{3}{8}$ | $\frac{7}{8}$ | $2\frac{7}{8}$ | 5 | 1 | $4\frac{1}{2}$ | $2\frac{1}{2}$ | $1\frac{1}{4}$ | $2\frac{1}{2}$ | $\frac{11}{16}$ | 67 |
| $5\frac{3}{4}$ | $8\frac{3}{4}$ | $\frac{15}{16}$ | 3 | 5 | 1 | $4\frac{3}{4}$ | $2\frac{1}{2}$ | $1\frac{1}{4}$ | $2\frac{1}{2}$ | $\frac{11}{16}$ | 70 |
| 6 | $9\frac{1}{8}$ | $\frac{7}{8}$ | 3 | $5\frac{1}{4}$ | 1 | $4\frac{7}{8}$ | $2\frac{3}{4}$ | $1\frac{3}{8}$ | $2\frac{3}{4}$ | $\frac{3}{4}$ | 72 |
| $6\frac{1}{4}$ | $9\frac{1}{2}$ | $\frac{7}{8}$ | $3\frac{1}{8}$ | $5\frac{1}{2}$ | 1 | $5\frac{1}{8}$ | $2\frac{3}{4}$ | $1\frac{3}{8}$ | $2\frac{3}{4}$ | $\frac{3}{4}$ | 72 |
| $6\frac{1}{2}$ | $9\frac{7}{8}$ | $\frac{7}{8}$ | $3\frac{1}{4}$ | $5\frac{5}{8}$ | 1 | $5\frac{3}{8}$ | $2\frac{3}{4}$ | $1\frac{3}{8}$ | $2\frac{3}{4}$ | $\frac{3}{4}$ | 72 |
| $6\frac{3}{4}$ | $10\frac{1}{4}$ | $\frac{7}{8}$ | $3\frac{3}{8}$ | $5\frac{7}{8}$ | 1 | $5\frac{1}{2}$ | $2\frac{3}{4}$ | $1\frac{3}{8}$ | $2\frac{3}{4}$ | $\frac{3}{4}$ | 72 |
| 7 | $10\frac{5}{8}$ | 1 | $3\frac{1}{2}$ | 6 | 1 | $5\frac{3}{4}$ | $2\frac{3}{4}$ | $1\frac{3}{8}$ | $2\frac{3}{4}$ | $\frac{3}{4}$ | 72 |
| $7\frac{1}{4}$ | 11 | 1 | $3\frac{5}{8}$ | $6\frac{1}{4}$ | 1 | 6 | $2\frac{3}{4}$ | $1\frac{3}{8}$ | $2\frac{3}{4}$ | $\frac{3}{4}$ | 72 |
| $7\frac{1}{2}$ | $11\frac{3}{8}$ | 1 | $3\frac{3}{4}$ | $6\frac{1}{2}$ | 1 | $6\frac{1}{4}$ | $2\frac{3}{4}$ | $1\frac{3}{8}$ | $2\frac{3}{4}$ | $\frac{3}{4}$ | 72 |
| $7\frac{3}{4}$ | $11\frac{3}{4}$ | 1 | $3\frac{7}{8}$ | $6\frac{5}{8}$ | 1 | $6\frac{3}{8}$ | $2\frac{3}{4}$ | $1\frac{3}{8}$ | $2\frac{3}{4}$ | $\frac{3}{4}$ | 72 |
| 8 | $12\frac{1}{8}$ | $1\frac{1}{8}$ | 4 | $6\frac{3}{4}$ | 1 | $6\frac{5}{8}$ | 3 | $1\frac{1}{2}$ | 3 | $\frac{3}{4}$ | 72 |
| $8\frac{1}{4}$ | $12\frac{1}{2}$ | $1\frac{1}{8}$ | $4\frac{1}{8}$ | 7 | 1 | $6\frac{3}{4}$ | 3 | $1\frac{1}{2}$ | 3 | $\frac{3}{4}$ | 72 |
| $8\frac{1}{2}$ | $12\frac{7}{8}$ | $1\frac{1}{8}$ | $4\frac{1}{4}$ | $7\frac{1}{4}$ | $1\frac{1}{8}$ | 7 | 3 | $1\frac{1}{2}$ | 3 | $\frac{3}{4}$ | 72 |
| $8\frac{3}{4}$ | $13\frac{1}{4}$ | $1\frac{1}{8}$ | $4\frac{3}{8}$ | $7\frac{3}{8}$ | $1\frac{1}{8}$ | $7\frac{1}{4}$ | 3 | $1\frac{1}{2}$ | 3 | $\frac{3}{4}$ | 72 |

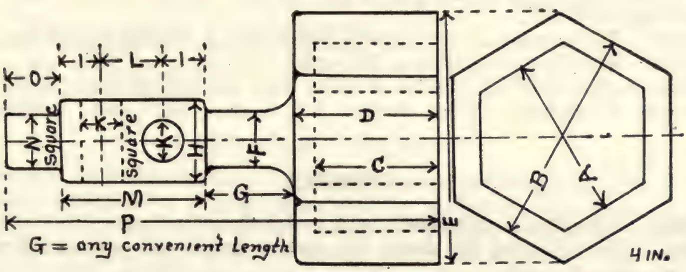
Box Wrenches for Hexagon Nuts—(*Cont.*)

| Diam. Bolt | A | B | C | D | E | F | G | H | I | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 | 13 5/8 | 1 3/16 | 4 1/2 | 7 5/8 | 1 1/8 | 7 3/8 | 3 | 1 1/2 | 3 | 3/4 | 72 |
| 9 1/4 | 14 | 1 3/16 | 4 5/8 | 7 7/8 | 1 1/8 | 7 5/8 | 3 | 1 1/2 | 3 | 3/4 | 72 |
| 9 1/2 | 14 3/8 | 1 1/4 | 4 3/4 | 8 | 1 1/8 | 7 7/8 | 3 | 1 1/2 | 3 | 3/4 | 72 |
| 9 3/4 | 14 3/4 | 1 1/4 | 4 7/8 | 8 1/4 | 1 1/8 | 8 | 3 | 1 1/2 | 3 | 3/4 | 72 |
| 10 | 15 1/8 | 1 5/16 | 5 | 8 3/8 | 1 1/8 | 8 1/4 | 3 | 1 1/2 | 3 | 7/8 | 72 |
| 10 1/4 | 15 1/2 | 1 5/16 | 5 1/8 | 8 5/8 | 1 1/8 | 8 1/2 | 3 | 1 1/2 | 3 | 7/8 | 72 |
| 10 1/2 | 15 7/8 | 1 5/16 | 5 1/4 | 8 7/8 | 1 1/8 | 8 3/4 | 3 | 1 1/2 | 3 | 7/8 | 72 |
| 10 3/4 | 16 1/4 | 1 3/8 | 5 3/8 | 9 | 1 1/8 | 8 7/8 | 3 | 1 1/2 | 3 | 7/8 | 72 |
| 11 | 16 5/8 | 1 3/8 | 5 1/2 | 9 1/4 | 1 1/4 | 9 1/8 | 3 | 1 1/2 | 3 | 7/8 | 72 |
| 11 1/2 | 17 3/8 | 1 3/8 | 5 3/4 | 9 5/8 | 1 1/4 | 9 1/2 | 3 | 1 1/2 | 3 | 7/8 | 72 |
| 12 | 18 1/8 | 1 1/2 | 6 | 10 | 1 1/4 | 10 | 3 | 1 1/2 | 3 | 7/8 | 72 |

## SOCKET WRENCH

When a nut or tap bolt is situated so that an ordinary open-end or box wrench can not be used, a socket wrench as shown in accompanying sketch may be employed. The design permits preliminary adjustment of nut by means of an ordinary wrench applied to the square provided at the free end, the final tightening being accomplished by means of a long bar inserted in one or other of the holes provided in the square head. A table of working dimensions is given.

Socket Wrench




| Bolt Dia. | A | B | C | D | E | F | H | I | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 5/8 | 2 1/8 | 1 1/4 | 1 1/2 | 2 1/2 | 1 | 1 3/4 | 15/16 | 7/8 | 1 3/8 | 3 1/4 | 1 | 1 |
| 1 1/8 | 1 13/16 | 2 3/16 | 1 3/8 | 1 11/16 | 2 9/16 | 1 | 1 3/4 | 15/16 | 7/8 | 1 3/8 | 3 1/4 | 1 | 1 |
| 1 1/4 | 2 | 2 5/8 | 1 1/2 | 1 13/16 | 3 | 1 1/8 | 2 | 1 | 1 | 1 1/2 | 3 1/2 | 1 1/8 | 1 1/8 |
| 1 3/8 | 2 3/16 | 2 13/16 | 1 5/8 | 2 | 3 1/4 | 1 1/4 | 2 | 1 | 1 | 1 1/2 | 3 1/2 | 1 1/8 | 1 1/4 |
| 1 1/2 | 2 3/8 | 3 1/16 | 1 3/4 | 2 1/8 | 3 9/16 | 1 1/4 | 2 1/4 | 1 1/8 | 1 1/8 | 1 5/8 | 3 7/8 | 1 1/4 | 1 1/4 |
| 1 5/8 | 2 9/16 | 3 5/16 | 2 | 2 5/16 | 3 13/16 | 1 3/8 | 2 1/4 | 1 1/8 | 1 1/8 | 1 5/8 | 3 7/8 | 1 1/4 | 1 3/8 |
| 1 3/4 | 2 3/4 | 3 1/2 | 2 1/8 | 2 7/16 | 4 1/16 | 1 1/2 | 2 1/2 | 1 1/4 | 1 1/4 | 1 3/4 | 4 1/4 | 1 1/4 | 1 1/2 |
| 1 7/8 | 2 15/16 | 3 3/4 | 1/4 | 2 5/8 | 4 3/8 | 1 5/8 | 2 1/2 | 1 5/16 | 1 1/4 | 1 3/4 | 4 3/8 | 1 1/4 | 1 5/8 |
| 2 | 3 1/8 | 4 | 2 3/8 | 2 3/4 | 4 5/8 | 1 5/8 | 2 3/4 | 1 3/8 | 1 3/8 | 1 7/8 | 4 5/8 | 1 3/8 | 1 5/8 |
| 2 1/4 | 3 1/2 | 4 7/16 | 2 5/8 | 3 | 5 1/8 | 1 3/4 | 2 3/4 | 1 3/8 | 1 3/8 | 1 7/8 | 4 5/8 | 1 3/8 | 1 3/4 |

SOCKET WRENCH—(*Cont.*)

| Bolt Dia. | A | B | C | D | E | F | H | I | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $2\frac{1}{2}$ | $3\frac{7}{8}$ | $4\frac{7}{8}$ | $2\frac{7}{8}$ | $3\frac{3}{8}$ | $5\frac{5}{8}$ | 2 | 3 | $1\frac{3}{8}$ | $1\frac{1}{2}$ | $2\frac{1}{8}$ | $4\frac{7}{8}$ | $1\frac{1}{2}$ | 2 |
| $2\frac{3}{4}$ | $4\frac{1}{4}$ | $5\frac{3}{8}$ | $3\frac{1}{8}$ | $3\frac{11}{16}$ | $6\frac{3}{16}$ | $2\frac{1}{8}$ | 3 | $1\frac{3}{8}$ | $1\frac{1}{2}$ | $2\frac{1}{8}$ | $4\frac{7}{8}$ | $1\frac{1}{2}$ | $2\frac{1}{8}$ |
| 3 | $4\frac{5}{8}$ | $5\frac{13}{16}$ | $3\frac{3}{8}$ | 4 | $6\frac{3}{4}$ | $2\frac{1}{4}$ | $3\frac{1}{4}$ | $1\frac{1}{2}$ | $1\frac{5}{8}$ | $2\frac{1}{4}$ | $5\frac{1}{4}$ | $1\frac{5}{8}$ | $2\frac{1}{4}$ |
| $3\frac{1}{4}$ | 5 | $6\frac{1}{4}$ | $3\frac{5}{8}$ | $4\frac{5}{16}$ | $7\frac{1}{4}$ | $2\frac{1}{2}$ | $3\frac{1}{4}$ | $1\frac{1}{2}$ | $1\frac{5}{8}$ | $2\frac{1}{4}$ | $5\frac{1}{4}$ | $1\frac{5}{8}$ | $2\frac{1}{2}$ |
| $3\frac{1}{2}$ | $5\frac{3}{8}$ | $6\frac{3}{4}$ | 4 | $4\frac{5}{8}$ | $7\frac{3}{4}$ | $2\frac{5}{8}$ | $3\frac{1}{2}$ | $1\frac{5}{8}$ | $1\frac{3}{4}$ | $2\frac{1}{2}$ | $5\frac{3}{4}$ | $1\frac{3}{4}$ | $2\frac{5}{8}$ |
| $3\frac{3}{4}$ | $5\frac{3}{4}$ | $7\frac{3}{16}$ | $4\frac{1}{4}$ | 5 | $8\frac{5}{16}$ | $2\frac{3}{4}$ | $3\frac{3}{4}$ | $1\frac{3}{4}$ | $1\frac{7}{8}$ | $2\frac{5}{8}$ | $6\frac{1}{8}$ | $1\frac{7}{8}$ | $2\frac{3}{4}$ |
| 4 | $6\frac{1}{8}$ | $7\frac{5}{8}$ | $4\frac{1}{2}$ | $5\frac{1}{4}$ | $8\frac{13}{16}$ | 3 | 4 | $1\frac{3}{4}$ | 2 | $2\frac{3}{4}$ | $6\frac{1}{4}$ | 2 | 3 |

# BLACK, GALVANIZED, AND COMPOSITION SPIKES

## NAVY DEPARTMENT

### BLACK AND GALVANIZED SPIKES

1. **Material.**—To be well made of wrought iron or mild steel, and clean-cut.

2. **Galvanizing.**—Galvanized spikes shall be properly protected by a uniform and smooth coating of zinc applied by the hot galvanizing process.

3. **Heads.**—To have diamond-shaped heads ¼ inch wider than the width of the spike.

4. **Tests.**—Spikes shall be capable of being bent through an angle of 180° to a diameter equal to the thickness of the spike without showing signs of cracking.

### COMPOSITION SPIKES

5. **Material.**—To be cast from a good grade of brass and be free from blow-holes, sand-holes, slag, and dirt.

6. **Heads.**—To have square countersunk heads with a slightly convex top. Heads to be ¼ inch wider than the widths of the spike.

7. **Tests.**—Spikes shall be capable of being bent through an angle of 60° without showing signs of cracking. When broken, the fracture shall show a homogeneous structure.

### GENERAL

8. **Points.**—All spikes shall be made with wedge-shaped points.

9. **Sizes.**—The following list shows the various lengths of commercial spikes for the different sizes of stock:

| Square Dimension | Length Over All, Inches | Square Dimension | Length Over All, Inches |
|---|---|---|---|
| *Inch* | | *Inch* | |
| $\frac{1}{4}$ | 3, $3\frac{1}{2}$, 4, $4\frac{1}{2}$, 5, $5\frac{1}{2}$, 6, 7, 8 | $\frac{1}{2}$ | 6, 7, 8, 9, 10, 12, 14, 16 |
| $\frac{5}{16}$ | 4, $4\frac{1}{2}$, 5, $5\frac{1}{2}$, 6, 7, 8 | $\frac{5}{8}$ | 10, 12, 14, 16 |
| $\frac{3}{8}$ | $4\frac{1}{2}$, 5, $5\frac{1}{2}$, 6, 7, 8, 9, 10, 12 | $\frac{3}{4}$ | 14, 16 |
| $\frac{7}{16}$ | 6, 7, 8, 9, 10, 12 | | |

10. **Packing and Marking.**—All spikes to be packed in kegs containing 100 pounds net. Each keg to be marked with the name of the manufacturer, the name of the material, the size, and net weight contained.

11. **Deliveries.**—All deliveries to be marked with the name of the material, the quantity, the name of the contractor, and the requisition or contract number under which delivery is made.

## SECTION 6

# GENERAL SPECIFICATIONS FOR INSPECTION OF MATERIAL

## NAVY DEPARTMENT

1. **General Specifications.**—These general specifications form part of leaflet specifications (when so stated in the leaflet) issued by the Navy Department. Further instructions to govern special cases may be issued by the bureau concerned.

2. **General Inspection and Test Requirements.**—All material for which tests are prescribed shall be inspected and tested by an inspector representing the bureau concerned, subject to restrictions mentioned herein or in the leaflet specifications, before being finally accepted by the Navy Department, attention being invited to paragraph 57. Shipment in advance of authority from the inspector will be at the risk of the manufacturer.

## GENERAL QUALITY

3. **Uniform Quality to be Supplied.**—All material shall be of uniform quality throughout the mass of each object, and free from all injurious defects. The discarding of inferior portions of ingots, treatment, and manufacture generally shall be so conducted as to insure uniformity in the quality of the metal of each heat, lot, or object submitted for inspection.

4. **Testing.**—All material for which tests are prescribed shall, when practicable for the bureau so to arrange, be tested and inspected at the place of manufacture, and shall be passed by the inspector, subject to the restrictions mentioned herein, as having complied with the particular specifications under which the material was ordered, before acceptance at the navy-yard or ship-yard.

5. **Special Material or Treatment.**—With the approval of the bureau concerned, special material or special treatment, or both, may be used to obtain the qualities specified in the leaflet specifications.

## CHEMICAL PROPERTIES

6. **Chemical Analysis—Analysis by Manufacturer.**—Drillings, turnings, or cuttings for chemical analysis must be fine, clean, and dry, and must be so taken as to represent fairly the heat, lot, ingot, or other object for which the analysis is taken. The inspector representing the bureau concerned may have these drillings, turnings, or cuttings taken from test coupons, or from any part or parts of the material represented by the analysis, provided in the latter case that by so doing the material will not be rendered unfit for use. Part of each sample for analysis shall be furnished the manufacturer if he desires it, the part retained by the inspector to be sufficient for three analyses. The inspector may require the manufacturer to furnish him with a chemical analysis of each sample with satisfactory evidence that such analysis has been properly and carefully made. A certificate from the party representing the manufacturer in making this analysis may be required.

7. **Analysis by Government.**—Chemical analyses which are made at the expense of the Government will be made as directed by the bureau concerned.

8. All metals of a proprietary nature shall be subjected to a chemical analysis. In case they differ from the specifications for standard mixtures they shall not be accepted unless authorized by the bureau concerned.

## PHYSICAL TESTS AND TEST PIECES

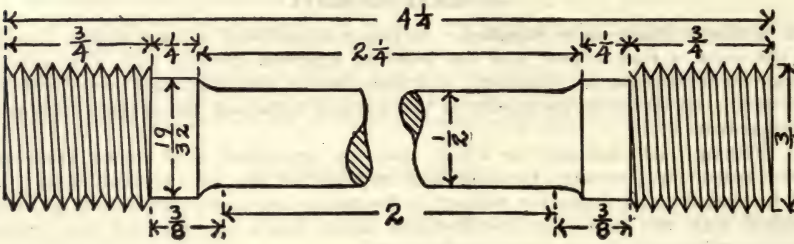
9. **Care and Calibration of Testing Machines.**—Tensile tests should be made by the use of a testing machine of standard make, kept in good condition. All knife edges

should be kept sharp and free from oil and dirt. Such a machine should be sensitive to a variation of load of one two-hundred-and-fiftieth of the load carried. Testing machines should be calibrated once in twelve months, and at such other times as may be considered necessary by the inspector representing the Navy Department.

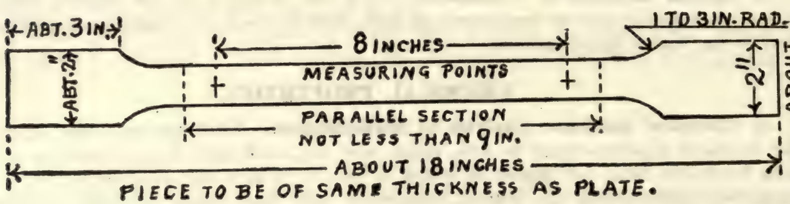
10. **Pulling Speed.**—Each tensile test piece shall be subjected to a direct tensile stress until it breaks, running at a pulling speed of not less than 1 inch and not more than 6 inches per minute for 8-inch test pieces and not less than $\frac{1}{2}$ inch and not more than 3 inches per minute for 2-inch test pieces. Increasing or decreasing the speed on the testing machine while the test piece is under stress will not be permitted.

11. **Interpretation of Terms.**—The elastic limit may be determined by observing the yield point as found by the drop of the beam or the halt of the gauge of the testing machine. The elongation is that determined after fracture. In the case of test pieces of rectangular section the reduction of area is to be measured by the product of the average width and thickness of the reduced area and not the minimum width and thickness.

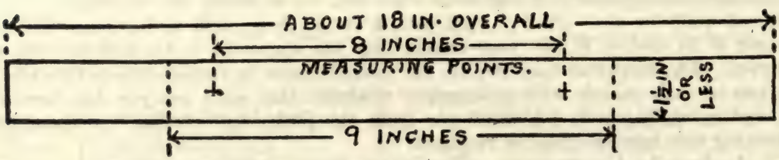
12. **Types of Test Pieces.**—Tensile test pieces shall have the dimensions shown in the following figures, which are the standard test pieces. If the manufacturer desires, he may be permitted to use the turned specimen unthreaded if a proper method of gripping the test piece is used. When specimens of Type 2 cannot be obtained from




TYPE 1.




TYPE 2.




TYPE 3.

shapes whose sizes do not permit of making other than straight-sided pieces, the use of Type 3 may be authorized by the inspector.

13. **Boiler Plates and Steam Pipes, Standard Size for Test Pieces.**—The width of tensile test pieces from plates and steam pipes over $\frac{5}{16}$ inch in thickness will be $1\frac{1}{2}$ inches, the thickness the same as the plate or steam pipe, and the length between measuring points 8 inches; under $\frac{5}{16}$ inch the width will be not over 2 inches, the thickness the same as the boiler plate or steam pipe, and the length between measuring points 2 inches.

14. **Full Size Test Pieces.**—All tests, when practicable, shall be made with pieces of the full size, thickness, or diameter of the material represented by such test specimens.

15. **Length of Test Pieces Between Measuring Points.**—Test pieces from blooms, large rolled bars exceeding 2 inches in diameter, forgings, and castings are to have a length between measuring points of 2 inches, as shown in figure 1 of paragraph 12. Other test pieces are to have a length between measuring points of 8 inches, as shown in figure 2 of paragraph 12, except as otherwise directed in these, or in the Navy Department leaflet specifications.

16. **Uniform Section of Test Pieces.**—Tensile test pieces shall be uniform in cross-section between measuring points.

17. **Variation of Area.**—A variation of 5 per cent above or below the standard area will be allowed in test pieces.

18. **Location of Test Pieces.**—All test pieces of forgings, and of rolled bars which are too large to be pulled in their full size, shall, unless otherwise specified, be taken at a distance from the longitudinal axis of the object equal to one-quarter of the greatest transverse dimension of the body of the object, not including palms and flanges.

19. **Test Pieces for Groups or Lots.**—Test pieces which represent heats or lots shall be taken, as nearly as the case will permit, so as to represent the metal which was nearest the top and bottom of the ingot; when practicable test pieces shall be taken from different ingots of a melt. Generally speaking, test pieces representing groups of lots should represent, as nearly as the case will permit, the worst material in that lot.

20. **Flaws in Test Pieces.**—Test pieces which show defective machining or which show flaws after breaking may be withdrawn at the request of the manufacturer and others taken under the direction of the inspector; also, new test pieces may be selected and tested to replace any which fail by breaking within a distance from the end measuring points equal to 25 per cent of the length over which the elongation is measured.

21. **Bending Test Pieces—Edges Rounded.**—Bending test pieces for blooms, large rolled bars (exceeding 2 inches in diameter), forgings and castings, shall be 1 inch wide by ½ inch thick. Specimens for cold bends for plates and shapes shall be rectangular in cross-section of the thickness of the material from which taken, and, when practicable, 12 inches long and of a width of 1½ to 2½ inches. The sheared edges will be removed to a depth of at least one-eighth of an inch, and the sides will be made smooth with a file, but no rounding of the edges will be permitted, except the removal of the feather edge. In the case of heavy ship plates of 60 pounds per square foot and over, specimens machined to ½ inch square section, center of section being half-way between outer surfaces, will be used for bends.

22. **Treatment of Test Pieces.**—Test pieces shall be subjected to the same treatment and processes as the material they represent and no other, except machining to size. They shall not be cut off until the plate or object shall have received final treatment and shall have been stamped by the inspector, except in cases which are specially mentioned in these or in the Navy Department leaflet specifications.

23. **Extra Material for Test Pieces Required Where Special Treatment Is Given.**—In the case of material which may require one or more retreatments, the objects must have attached sufficient material to enable the cutting of test pieces after each treatment. The manufacturer will be allowed only three official tests. In all cases where the test specimens fail to meet the requirements on the third test, the material represented by the specimens shall be rejected, except where the inspector recommends to the bureau concerned that further treatment or testing be authorized. In special cases general exceptions to the above may be made by the bureau concerned.

24. **Other Special Heat Treatment.**—If the material is to be subjected to any special or general heat treatment to secure physical properties required, the inspector will make such additional tests as may be required to show that the treatment has left the material of uniform quality throughout.

25. **Material Which May Be Exempt from Tests.**—Material called for in Navy Department leaflet specifications specified to be of ordinary commercial quality will not be subject to tests or analysis unless there is reason to doubt that it is of suitable quality. If doubt should arise as to the quality of the material the inspector may

make such tests as he deems necessary to determine the equality, either at the works of the manufacturer or at the point of delivery.

26. **All Material Subject to Inspection.**—Material exempt from tests shall be inspected for injurious defects, workmanship, and for accuracy of dimensions. This inspection will be made either at the point of shipment or at point of delivery, as may be designated.

27. **Tests for Special Material.**—Tests may be prescibed by the bureau concerned for the inspection of material for which tests are not specified in the leaflet specifications.

28. **Tests for Uniformity of Material.**—The inspector may require from time to time such additional tests as he may deem necessary to determine the uniformity of the material and to insure material of the desired quality.

29. **When Heat Number Is Doubtful.**—Manufacturers of steel material desiring to avail themselves of melt tests for acceptance of material must so arrange their working and handling of the material that the inspector may at all times identify with perfect certainty any portion of the melt which is offered for inspection. In case the inspector cannot definitely determine the identity of the melt from which a plate, forging, casting, or other object is made, such plate, forging, casting, or other object shall be tested singly, and, before acceptance, must conform to the chemical and physical requirements specified for its class.

30. **Annealing.**—The whole of an object specified to be annealed shall be subject to the same proper degree of heat at the same time, or, when necessary, to a uniformly graded degree of heat which will produce a uniform degree of anneal. The number of hours requisite for raising the object to sufficient temperature, the length of time during which it shall be soaked at its maximum heat, and the period for slow cooling in the furnace may be prescribed by the bureau.

31. **Treatment of Lots.**—Objects tested as a lot after being treated shall be from the same melt.

32. **Weights.**—The weights of all materials shall be obtained before shipment and shall be accurately entered upon the proper invoices. Accurate standard scales which have been frequently tested shall be used, and an inspector will witness testing and weighing when possible.

33. **Methods of Weighing.**—Weighing will be done by one of the following methods:

(a) Weighing each individual piece.

(b) Weighing lots or parts of lots of material of same size which is inspected by lots.

34. **Methods of Checking.**—Checking of weights will be done frequently, when practicable, or when ordered by the bureau, by the following methods:

(a) Reweighing individual pieces.

(b) Reweighing lots or parts of lots of material weighed individually or by lots.

(c) Gauging and measuring.

(d) Weighing full car.

35. When the method of checking by weighing the full car is used, the manufacturer shall furnish the inspector for each carload a statement showing the gross, tare, and net weights of the car, and the total weights of the individual pieces on the car if it is practicable to obtain same. If the net weight of the car varies by more than 1 per cent from the weight obtained by totaling the weight of individual pieces or of the lots, if weighed by lots, the material, if ordered by the department, shall be paid for on the basis of the lesser weight, or the manufacturer may run down the error by removing the material from the car and reweighing, or by other means which will satisfy the inspector as to the actual weight of the material.

36. **Contractors' and Other Orders for Inspection of Material.**—At a ship-building yard the ship-builder shall furnish the bureau's representative at his ship-yard with quadruplicate copies of every order to manufacturers for all materials which are to be inspected at the plant of the manufacturer by an inspector representing the bureau concerned.

37. **Material Which Is To Be Inspected Without Instructions.**—Any material which a manufacturer may present to a naval inspector shall be inspected, provided it is without doubt material that is intended for the Navy Department. In such cases the inspector shall call upon the manufacturer to exhibit the original orders or contracts,

or true copies of such orders or contracts, from the representatives of the Navy Department, showing the object, quantity, specifications, and other details descriptive of the material. If inspection has not been authorized by the bureau, it should be reported to the bureau concerned, together with copies of the correspondence involved.

38 (a). **Subletting.**—A contractor when subletting a part or whole of his contract shall notify the bureau concerned through the local inspector; shall give the subcontractor full information as to the fact that the material is subject to naval inspection, and the number and the date of the specifications.

38 (b). The subcontractor shall fully comply with all the requirements of the contract specifications concerning quality, dimensions, method of inspection, rejection, replacement, shipment, etc.

38 (c). **Orders from Contractors to Subcontractors and Manufacturers.**—Contractors and subcontractors shall furnish the inspector representing the bureau concerned in their district quadruplicate copies of all orders placed with manufacturers for materials, stating, when possible, the purpose of each item ordered and the specifications for the same. Such orders shall state explicitly what treatment, other than machining, is to be given the material after leaving the manufacturers' works. In all cases these orders shall contain the number of the original contract of which these constitute suborders.

39. **Inspection During Manufacture.**—The inspector should keep in touch with the work throughout its manufacture and should make such efforts as are practicable to secure delivery within the contract time. If at any time it should appear that preference is given to commercial work, thereby causing delay in Government work, a special report of the circumstances should at once be made direct to the bureau concerned.

## ORDERS, LISTS, AND INVOICES

40. **Contractors to Supply Blue-prints.**—Blue-prints or sketches forming part of contractors' or subcontractors' orders shall be supplied by contractors in triplicate.

41. **Matters to be Referred to Inspectors.**—Correspondence relating to material should be carried on directly with the inspector having cognizance of the inspection. When in cases of rejection contractors consider it necessary to appeal to the bureau concerned, the correspondence should be forwarded via the inspector.

42. **Information to be Furnished by Manufacturer.**—Manufacturers shall furnish the inspector copies of mill orders, which shall be given separately for each vessel and which shall state the following:

(a) The order or schedule number and name or designation of vessel.

(b) The leaflet number and date of the department's specifications under which the material is ordered.

(c) The kind or grade of material of each object.

(d) The purpose for which intended, if practicable.

(e) The ship-yard's location mark.

(f) The number and quantity of each item and the essential dimensions.

(g) The estimated weight of each plate, lot of shapes, forgings, castings, or other objects.

(h) Information as to marking and arranging ingots (the marking to be such as to make identification easy).

(i) The amount of discard at top and bottom of ingots (when required by inspector).

(j) The number and height of heads and risers (when required by inspector).

43. **Shipment of Material.**—No material shall be shipped by a manufacturer or subcontractor except by direction of the inspector or other authorized representative of the bureau concerned.

44. **Invoices to be Promptly Prepared by Manufacturers.**—The manufacturer shall furnish the inspector, immediately after a shipment of material, with invoices in quadruplicate covering each shipment. The information called for below may be submitted on a form furnished by the bureau or inspector concerned, or on a manufacturer's approved form. Manufacturers should furnish this information promptly,

as any delay in so doing will cause delay in acceptance of material at destination and in the preparation of vouchers incident to the payment for the same.

Invoices or shipping reports should contain the following information:

The name of the manufacturer.

The name and location of the navy-yard or ship-yard ordering or receiving the material.

The name or designation of the vessel or stock concerned, the date of shipment, car initials, and number.

The order, schedule number, or item number.

The grade or kind of material of each object.

The location marks designated by the navy-yard or ship-yard.

The name of road, car number local, line or steamer, truck, etc.

The number of articles on the item and dimensions of each object in inches, the gauge for plates in pounds per square foot, and for shapes in pounds per linear foot.

The actual and estimated weight of each plate or lot of like shapes, rivets, or other objects, and the melt and serial number of each plate or forging, the melt number only for other objects.

45. **Date of Shipping Report.**—The date of a shipping report should be the date of shipment.

46. **Inspection Stamps.**—Each object accepted shall be clearly and indelibly marked with four separate stamps: (1) The private stamp of the inspector; (2) stamp of the manufacturer; (3) identification number; (4) the regulation Government pass stamp. The last shall not be stamped on any material until it has been inspected and passed ready for shipment. In case of small articles passed and packed in bulk the above-mentioned stamps shall be placed on the boxing or packing material of the object. If the objects are bundled these stamps will be placed on tags securely wired to the bundles. Exceptions to the above may be made, when considered necessary, at the discretion of the inspector.

47. **Sealing of Cars.**—In special cases, where material is shipped in carload lots, in sealed cars, the inspector will witness the loading of the car and place the regulation pass stamp on the seals which seal the car. Where the material is of such a nature that stamping would injure it, the marking will be done with stencils bearing the initials of the inspector and the regulation pass stamp.

48. **Acceptance of Material.**—No material will be received at a naval station, navy-yard, or ship-building yard unless it bears, either on its surface or that of its packing, these stamps as evidence that it has passed inspection, nor shall it be finally accepted until after the receipt of a duly certified report of the inspector by whose office the inspection was made.

49. **Removal of Stamps Without Authority.**—The removal of any Government stamp from material without authority of the inspector will be sufficient reason for the rejection of that material.

50. **Stamps on Large, Rough Work.**—Each object which has passed inspection shall be clearly marked with the necessary stamps, and these stamps, on large, rough work, shall be encircled by a ring of paint.

51. **Marking Ingots, Etc.**—Ingots, blooms, and other material intended to be cut up shall have the stamps above-mentioned put on in three places, viz., near each end and near the middle, and encircled by paint marks.

52. **Stamps on Boxes.**—In the case of small articles passed and packed in bulk, or in the case of material which would be injured by stamping, the above-mentioned stamps shall be applied to the boxing or packing material of the articles, or may be done with stencils bearing the inspector's initials and the regulation pass stamp.

## REJECTION AT DESTINATION

53. **Rejection After Having Passed Inspection.**—Material may be rejected at a navy-yard or other place of delivery for defects either existing on arrival or developed in working or storage for which the contractor is clearly responsible, even though such

# GENERAL SPECIFICATIONS FOR INSPECTION OF MATERIAL

UNDER THE COGNIZANCE OF THE BUREAUS OF CONSTRUCTION AND REPAIR, STEAM ENGINEERING, AND ORDNANCE

Issued by the Navy Department, October, 1913

## INDEX OF GENERAL SPECIFICATIONS FOR INSPECTION OF MATERIAL

material may have passed previous inspection by the inspector at the place of manufacture. In such cases the manufacturer must make good any material rejected.

### EXPENSE

54. **Handling Material.**—All handling of material necessary for purposes of inspection shall be done at the expense of the contractor.

55. **Making Tests.**—All test specimens necessary for the determination of the qualities of material shall be prepared and tested at the expense of the contractor.

### OFFICE AND INSPECTORS

56. **Access to Work.**—The department shall have the right to keep inspectors at the works, who shall have free access at all times to all parts thereof and be permitted to examine the raw material and to witness the processes of manufacture.

57. **Information and Facilities.**—Contractors and manufacturers shall furnish all the information and facilities the inspector may require for proper inspection under these specifications. The department is at liberty at any time to require additional information.

58. **Office and Furniture.**—Inspection and tests shall be made when practicable at the place of manufacture, and any firm doing work for the Navy that requires inspection shall furnish the inspectors, free of expense, with such facilities as may be necessary for the proper transaction of their business as the agents of the Government. When requested by the bureau, inspectors shall be supplied free with suitable office and laboratory room, and such plain office and laboratory furniture as may be necessary for the proper transaction of their business.

59. **Specifications, Where Obtainable.**—NOTE.—Copies of the above specifications can be obtained upon application to the various Navy pay offices or to the Bureau of Supplies and Accounts, Navy Department, Washington, D. C.

60. **References.**—(Ord., C. & R., and S. E.) C. & R., SPS, May 5, 1913.
S. & A., 380–5.

## GENERAL SPECIFICATIONS FOR INSPECTION OF RUBBER MATERIAL

### NAVY DEPARTMENT

September 1, 1914

1. **Temperature of Room.**—All tests of the rubber parts shall be made in a room the temperature of which is not below 65° F., and the range of temperature not to vary beyond the limits of 65° F. to 90° F., if practicable; the tests shall not be made in the cold, nor shall any tests be made until the article to be tested has been standing 48 hours after vulcanization.

2. **Tests of Adhesion of Rubber Parts to Cotton or Fabric Parts.**—(a) APPARATUS.—A standard testing table suitable for the purpose shall be used.

(b) PREPARATION OF TEST PIECE.—In making the test a section of the article shall be cut.

In testing hose the section shall be cut transversely, unless the diameter of the hose is too small to be practical for this test, in which case it shall be cut longitudinally.

When testing belting, packing, or gasket material, it may be cut in any direction.

When testing cotton rubber-lined hose the test piece shall be prepared by cutting directly through the section, so as to lay out upon the table a piece measuring the full length of the circumference of the hose and 2 inches in width. On this piece two parallel cuts $1\frac{1}{2}$ inches apart shall be made by cutting through the lining only and not injuring the cotton cover. This strip shall be started at one end to the extent of about $1\frac{1}{2}$ inches. The cotton cover only shall be fastened in the clamps.

When testing a fabric-plied hose the section shall be 1 inch in width. The piece shall be separated until the part next to the rubber cover shall be loosened. The section shall then be placed on a mandrel whose diameter is the same as that of the inside of the hose to be tested.

When testing packing, the piece shall be prepared as in the case of cotton rubber-lined hose, unless the thickness of rubber is greater than $\frac{1}{8}$ inch, under which conditions the piece shall be prepared in such a way that the rubber part is to be clamped at the top and held immovable while the weight, as described below, is to be clamped to the fabric.

When testing belting, the test strip is to consist of 2 plies of fabric only, one ply being held in the stationary grip, with weights suspended freely from the other ply.

Square Tuck's packing shall be tested in the same manner as is specified for testing the friction between the plies of a belt.

The friction in round Tuck's packing shall be tested by the same method as is used in fabric-plied hose, the core being drilled out to permit the insertion of a mandrel. Whenever the core is $\frac{3}{16}$ inch or less in diameter it shall be tested in its original shape. When it is over $\frac{3}{16}$ inch in diameter a piece 6 inches long shall be separated from the fabric and cut and buffed on four opposite sides to form a square section $\frac{1}{8}$ by $\frac{1}{8}$ inch in the center of the test piece. The $\frac{1}{8}$ inch square shall be at least 1 inch in length.

In testing the friction of belting the load should be applied at right angles to the plane of separation, or the test strip should consist of only 2 plies of fabric, 1 ply being held in the stationary grip with the weight suspended freely from the other ply. By this means the effect of the thickness of the belt may be eliminated.

(c) Performance of the Tests.—Having thus fastened the test piece, the clamp ring shall be slipped upon the mandrel, or in the case of fabric-plied hose, the test piece shall be slipped upon the mandrel. The free-moving clamp shall be tightly fastened to the free end and the weight supported upon a movable table hooked over the hook in the clamp. The weight and the clamp together shall be exactly equal to the weight called for in the specifications.

The weight then supported by the movable table of the testing machine shall be lowered until the clamp and free end of the hose are just taut. An indelible pencil mark shall be placed upon the separating layers of the test piece, and by quickly loosening the thumb-screw supporting the table, it shall be allowed to fall, leaving the weight freely suspended. In every case this shall be done without a jerk. The time shall be read at the moment of freeing the weight and at the moment of re-marking. The weight shall be allowed to act upon the test piece for ten minutes, at the end of which time an indelible pencil mark shall be placed again upon the separating layers of the test piece. The movable table shall then be brought up to hold the weight, the test piece removed and laid upon the table, and the distance between the pencil marks shall be measured by means of a certified rule accurately graduated in decimals of an inch. The distance between the marks shall be recorded as the number of inches of separation in ten minutes, from which shall be computed the rate in inches per minute.

3. **Tests of Rubber Parts.**—(a) Test Piece Preparation.—For hose, a section 1 inch in width shall be cut. For belting, packing, and sheet gaskets a piece 1 inch in width and 6 inches in length shall be cut in any direction. The rubber parts shall be carefully separated from the fabric of this piece, using benzine in small amount if necessary. The benzine used in this case shall always be 76° Baumé, free from oil.

In case of articles to be tested, such as washers, ferrules, and moulded gaskets, which are of such peculiar shape that the above methods do not apply, small sample pieces shall be sent with each delivery. These sample pieces shall be 8 inches in length, $1\frac{1}{2}$ inches in width, and $\frac{1}{8}$ inch in thickness, unless otherwise specified. These sample pieces shall be guaranteed by the manufacturer to truly represent the average composition and cure of the article delivered. Test pieces shall be cut from these samples as described below. From these 1-inch sections, or from sample pieces thus prepared, a test piece shall be cut by a die. The dimensions of the test piece shall be indicated in each specification. It is the intention to have the cross-section area at the constricted part approximately $\frac{1}{32}$ square inch. The backing or cloth impression shall be removed from the test piece by buffing for determining the cross-section area. No

test shall be performed until the piece has been allowed to stand for one hour after removal from the article, if it has in any way been in contact with benzine.

(b) **Testing Machine.**—JAWS.—The jaws must tighten automatically and exert a pressure proportionate to the applied tension. The rate of speed of separation of the jaws is to be uniformly 20 inches per minute. The jaw must exert a uniform pressure across the width of the test piece, regardless of any variation in the thickness of the rubber.

The test machine should be suitable to carry out the necessary tests, and should be standardized in accordance with the latest approved designs so far as practicable.

(c) **Making of the Measurements.**—TAKING OF TIME.—All measurements of time shall be taken by means of a stop watch. The fundamental methods of testing are so made throughout the entire rubber specifications that the following procedure shall be uniform: After placing any test piece in the machine ready for stretching the piece shall be drawn just taut and the stop watch started at the instant of the beginning of the stretch. The piece shall then be held for ten minutes at a specified distance and the time shall be again noted at the moment the piece is released. This moment is simultaneously the beginning of the period of rest. The measurement is then to be taken at the instant of expiration of the second ten minutes.

(d) MEASUREMENT OF ELONGATION.—Marks 2 inches apart shall be placed on the test piece by means of a marker. These marks shall be at right angles to the direction of pull of the piece in the machine. Great care shall be taken: (1) That the marks are not too wide, and that (2) at the time of marking the piece shall have been lying for a sufficiently long time to be completely at rest on a wooden table which has been at the temperature of the room mentioned in paragraph 1 herein. The marks shall be placed on the smooth side; that is, in no case on the side which is corrugated due to its impression taken from the fabric.

After clamping the test piece in the jaws of the machine the movable jaw shall be so adjusted with the pointer reading zero on the scale that the test piece is just taut, but not under tension. The operator shall throw on the current to start the screw and when ready throw in the engaging lever to start the jaws. He shall keep the elongation scale pointers opposite the outside edges of the marks on the piece. To stop the motion at the desired elongation or upon the break of the piece, the jaws shall be disengaged from the screw.

The accuracy with which the elongation measurements are made will depend upon the accuracy with which the operator keeps the two pointers opposite the outside edge of the marks on the test piece.

The elongation shall be reported in inches, including the original 2 inches; that is, if the rupture occurs at 11 inches, or 12 inches, or 13 inches, it will indicate that the stretch has been 2 to 11, 2 to 12, or 2 to 13. After the piece has been removed from the machine, the permanent elongation or recovery shall be measured by laying it upon a wooden table, which is of the temperature of the room, and allowing it to rest for ten minutes. Immediately upon the expiration of the ten minutes, a rule graduated to $\frac{1}{32}$ inch shall be laid upon the piece and the elongation read in $\frac{1}{32}$ of an inch, measuring the outside of the marks.

The per cent of elongation of the test piece above the original 2 inches shall represent its permanent elongation.

(e) **Tensile Strength.**—The tensile strength shall be determined by stretching a test piece not previously tested in the tensile machine until it breaks. If the test piece breaks outside the marks, or in the wider portions of the piece, and the tensile is much below that called for in the specifications, it is probable that this piece is faulty and that another would meet the requirements. If the piece breaks outside the marks and yet shows a tensile above that called for in the specifications, it is probable that the piece is faulty and that its true tensile strength is higher than indicated. Since its recorded tensile strength exceeds that called for in the specifications, however, it shall not be necessary to retest.

Before any tests are made, the width of the test piece shall be determined at 3 points, equidistant between the marks. The backing or irregularities of fabric impression shall be stripped or buffed off and the thickness measured with the backing

removed. It shall be determined at 3 points equidistant between the marks on the test piece, by means of a standard spring gauge micrometer, the disks of which are $\frac{1}{2}$ inch in diameter. The measurements used in the computation of tensile strength shall be those read nearest the point of break. The disk of the micrometer shall be $\frac{1}{4}$ inch in diameter when measuring thickness of the tube of all hose which has an inside diameter of 1 inch or under.

(f) Initial Stress.—During the elongation and recovery test the initial stress shall be taken by connecting a spring balance with the piece under test. The number of pounds read on the balance at the maximum stretch shall then be computed in pounds per square inch, and expressed as "initial stress."

4. **Pressure Tests.**—(a) The hose shall be stretched out for inspection, connected to the pump, and filled with water, leaving the air cock open to allow the air to escape. The air cock shall then be closed and a pressure of 10 pounds per square inch applied. The test is then begun by taking original measurements without releasing the pressure.

(b) All pressure tests shall be made by using a hand or power water pump standardized gauge. The increase in pressure shall be made at the rate of 100 pounds per minute, and the hose under test shall be held for measurement not more than 2 minutes, unless otherwise called for in the specifications.

5. **Composition.**—(a) Friction.—Wherever, in the detail specifications, friction is mentioned, it is understood that it should be made from a compound which will neither yield to acetone any organic constituent foreign to Hevea rubbers nor contain more sulphur than is necessary for vulcanizing, so that the percentage of sulphur in the rubber layers shall not be raised beyond the permissible amount.

(b) Material.—The ............ shall be properly vulcanized, and be made
(Article.)
from and have all the characteristics of a compound containing not less than ...... per cent of washed and dried, fine Para rubber, not more than ...... per cent of sulphur, with the remainder suitable, dry, inorganic, mineral fillers. The mineral fillers may contain barytes, but shall be practically free from sulphur in other forms and from any substance likely to have a deleterious effect on the rubber compound. The sulphur in barytes will not be included in the allowable sulphur content.

(c) Sample for Chemical Analysis.—A sample taken for chemical analysis shall be free from backing.

6. **Average Reading.**—Since the physical properties of rubber vary noticeably in any given product, it may occasionally happen that tests are made upon a sample which will be of poor quality. The hose, belting, or packing will, as a whole, meet the requirements of the standard, but the particular piece taken may fall somewhat below it. To reject or accept a lot of hose because of its failure to meet one test under specifications would therefore be unfair. For this reason acceptance or rejection of an item offered for delivery shall be based on the average of at least four determinations for each quantity. In arriving at these averages no weight shall be given to tests which are obviously in error, and do not represent true average conditions, e.g., cases in which the tensile strength is low on account of a small flaw in the article or the friction is low on account of a small flaw in the friction part. In other words, the intent of the specifications is to insure a high-grade article in every particular, and the intent of the methods of testing is to see that the article as a whole is of this high standard.

Deliveries of hose, packing, etc., which regularly meet certain provisions of the specifications, but quite as regularly fail to meet others, are obviously improperly made and should be rejected.

7. **Rejections and Replacements.**—All rubber materials shall be inspected and tested, so far as practicable, at the point of manufacture. In case of rejection the contractor shall be allowed ample opportunity to test the rejected articles before replacing them. Articles found to be defective within the guaranteed time required in the specifications under which they were purchased may be examined and tested by the contractor before replacements are made.

# THE TESTING OF MECHANICAL RUBBER GOODS

## BUREAU OF STANDARDS

The principal sources of crude rubber are South America, Central America, Africa, and Asia. The Amazon district of South America is noted for the excellent quality of its rubber. In addition, much rubber is secured from plantations where rubber-bearing trees are cultivated according to scientific principles. This is generally known as "plantation rubber."

Briefly stated, rubber is obtained in the following way: Incisions are made in the bark of the trees, and receptacles are placed under the incisions to collect the gradual flow of latex. The custom usually followed by natives is to coagulate or dry the latex by means of smoke or merely by exposure to the air. "Plantation latex" is coagulated by the addition of acid, after which the rubber is washed, sheeted, dried, and sometimes smoked. The smoking process has been adopted in an attempt to secure the valuable properties possessed by the wild rubbers, which are coagulated by smoking.

Crude rubber is greatly affected by changes in temperature, becoming stiff when cold, and soft and sticky when warm.

**Vulcanizing.**—Goodyear discovered, in 1839, that if crude rubber to which sulphur had been added was heated to a temperature above the melting point of sulphur it combined with the sulphur, became very much less susceptible to temperature changes, and at the same time gained both in strength and elasticity. This important discovery may be said to mark the practical beginning of the rubber industry, although crude rubber had been previously used to a limited extent as a waterproofing material. The process is popularly known as "vulcanizing."

**Rubber Substitutes.**—No true rubber substitute—that is, no material possessing all the properties of rubber—has yet been produced on a commercial scale. There are a number of so-called substitutes, however, that may be mixed with rubber to advantage in the production of certain articles. Such materials are produced from vegetable oils, by processes of vulcanization or oxidation.

**Reclaimed Rubber.**—On account of the large amount of waste vulcanized rubber or scrap available, and the high cost of crude rubber, the reclaiming of rubber has assumed such proportions as to constitute an industry in itself. By "reclaimed rubber" is not meant devulcanized rubber, although in some cases the free sulphur is removed. No process has yet been developed by which the process of vulcanization can be reversed and crude rubber reclaimed.

The old method of reclaiming consisted in grinding the scrap and removing the fibers and particles of metal, and other waste material, after which the rubber was mixed with oil, heated in ovens, and sheeted. In a more modern process, the fibrous materials are destroyed by treatment with acid, after which the scrap is heated in ovens.

A third method, known as the alkali process, which is carried out on an extensive scale, may be briefly outlined as follows: Old rubber is ground between rollers, particles of iron are removed by magnets, and the ground material is screened. The rubber is then heated in iron vessels containing an alkali solution, by which means free sulphur is removed and the fibrous matter destroyed, after which it is thoroughly washed to remove the alkali and dried by steam coils. It is then mixed between rollers without the addition of oil, and sheeted.

It is said that rubber reclaimed by this process from carefully selected scrap is superior to some of the lower grades of crude rubber.

**Manufacture.**—Crude rubber as received at the factory is in the form of lumps of irregular shape and size, and contains varying amounts of impurities which have to be removed. These lumps are placed in a vat containing water, and boiled in order that they may become sufficiently soft to be handled by the washing rolls.

**Breaking Down and Washing.**—The washing rolls consist of two steel cylinders, about 12 to 18 inches in diameter, which revolve in opposite directions and at different speeds, their axes being parallel and in the same horizontal plane. These rolls are corrugated, and as the crude rubber is fed between them their action is such as to

masticate the soft lumps and expose the impurities, which are washed out by a series of water jets and collected in a pan under the rolls. Two sets of rolls are used in this process. The first set breaks down the lumps while a large part of the impurities is washed out, and the second set, in which the rolls are closer together, completes the process of washing. After a sufficient number of passages through the rolls, the washed rubber has the form of a rough sheet of irregular shape, and contains considerable water, which must be removed before vulcanization.

**Drying.**—There are two methods in use for removing the water from washed rubber. The first is to hang the rubber sheets in a warm dry place—usually the attic—steam-heated pipes being used to maintain the proper temperature during cold weather. This method is usually employed, as less skill is required than in the second and quicker method, in which vacuum heaters are used. The rubber having been dried as described above, is "broken down" or worked through smooth steam-heated rolls, by which process it is rendered soft and plastic.

**Compounding and Mixing.**—The rubber is now in condition to be compounded or mixed with sulphur and mineral matter, and with reclaimed rubber or rubber substitutes, if such are used.

The ingredients required for a batch having been weighed out in the definite proportions to produce a compound of the desired quality, the mixing is done with

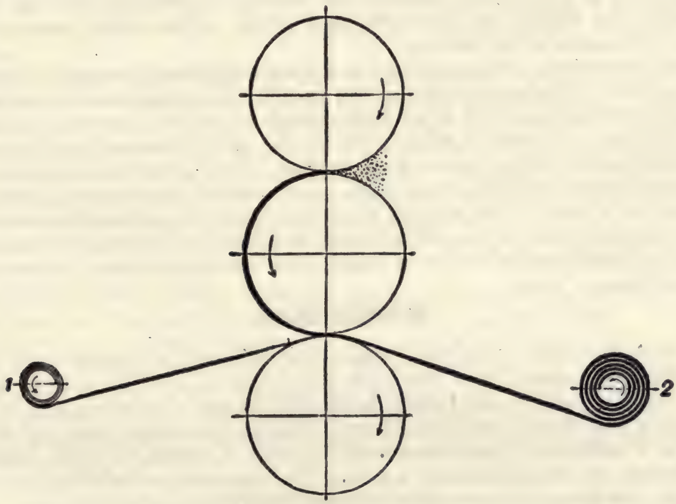



Fig. 1.—Diagram Showing Operation of Calender Rolls.

smooth rolls operated as in the washing process. Both steam and water connections are provided so that the temperature of the rolls may be regulated to suit the condition of the rubber as it is being worked. The rubber gradually absorbs the sulphur and fillers which are added by an attendant. Such material as passes through without being incorporated with the rubber is collected in a pan and returned to the rolls. The temperature of the rolls is so regulated that as the operation of mixing proceeds the compound sticks to one of them in the form of a sheet. This sheet is cut with a knife, folded upon itself, and passed through the rolls again, the operation being repeated until the material shows a uniform color and is as nearly homogeneous as it is practicable to make it.

**Sheeting.**—The next step in the process of manufacture depends upon the purpose for which the rubber is intended. If sheet rubber is being made, as for packing or for the tubes and covers of hose, the compound coming from the mixing rolls is passed

through calender rolls. The calender consists of three steam-heated rolls, one above the other, which are so geared together that the middle roll revolves in the opposite direction from that of the other two. The rolls may be adjusted to form sheets of different thickness. The skeleton diagram in Fig. 1 shows the method of operation.

Rubber is fed between the top and middle rolls, and by a proper regulation of temperatures the sheet adheres to the middle one while the top one remains clean. A strip of cloth is taken from the reel 1 and passed between the middle and bottom rolls to the reel 2. The sheeted rubber as it passes between the middle and bottom rolls is received by the cloth and carried to the reel 2, upon which they are wound together, the cloth preventing the layers of rubber from adhering. The sheet may be cut into strips of any desired width by knives which press against the middle roll.

Sometimes several calendered sheets are rolled together to form a single sheet. The rubber is now ready to be vulcanized or worked into hose or other fabricated articles.

**"Friction."**—What is known as "friction" in the case of rubber hose, rubber belting, and other articles, which are made up with superimposed layers of canvas, is the soft rubber compound which is applied to the canvas and by means of which the different layers or plies are held together.

The canvas is first dried by being passed over steam-heated rolls, after which the friction is applied by means of rolls which are operated in the manner just described, and illustrated in Fig. 1.

In the case of the friction calender, the bottom roll revolves at about two-thirds the speed of the middle roll, thus causing a wiping action which forces the friction well into the meshes of the canvas.

**Cutting the Canvas.**—Canvas for use in making rubber hose is usually cut on the bias from strips 40 to 42 inches wide, into pieces long enough so that when placed end to end and lapped, the resulting strip is just wide enough to produce the necessary number of plies on the hose. There is no waste when cutting on the bias, and the finished hose is more flexible than when the canvas is cut straight. On the other hand, when the canvas is cut straight there is more or less waste on account of the last strip, which is often too narrow to be used. This method of cutting, however, produces the stronger hose, and a hose which will not expand as much, and which will elongate under pressure, avoiding the objectionable feature of longitudinal contraction which is noticed in hose made with bias-cut duck.

## RUBBER HOSE

The ordinary "plied" hose with rubber tube and cover is manufactured as follows:

**1. Tubes and Covers.**—For low-grade water hose of small diameter it is usual to form the tubes by passing the rubber compound through a die which may be adjusted to produce a wall of any desired thickness. The rubber coming from the mixing rolls must be at a sufficiently high temperature to make it plastic, in which condition it is forced through the die by means of a worm. The operation is similar to that of a "soft mud" brick machine, and the tube as it comes from the die is carried away on an endless belt. These tubes are placed on steel mandrels by a rather ingenious process, as follows:

The mandrel, which is about 52 feet long, is placed on an endless belt and held stationary. Powdered talc is blown into the tube to act as a lubricant and to prevent it from sticking to the mandrel during vulcanization. One end of the tube having been placed over the mandrel, air pressure is applied at the other end, sufficient to expand the tube slightly. The belt is now set in motion, and the tube as it is fed onto the belt floats over the mandrel on a cushion of air. In the case of high-grade hose and hose of large diameter, the tube is made from a strip of sheet rubber, cut with a "skive" or tapering cut, which is wrapped over the mandrel by hand, the edges being lapped and pressed flat by means of a small hand roller.

In either case, the cover is made from a strip of sheet rubber just wide enough to pass once around the hose and form a narrow lap.

To ensure firm adhesion between the tube and canvas, the former is cleaned with gasoline, preparatory to receiving the frictioned canvas.

**2. "Making up" the Hose.**—Water hose of small diameter is usually wrapped by

machinery consisting of three rolls about 2 inches in diameter and slightly more than 50 feet long. The two bottom rolls lie in the same horizontal plane and the top roll, which is just above and between the other two, may be raised while the mandrel carrying the tube to be wrapped is being placed on the bottom rolls. The top roll is now lowered onto the tube, which is held firmly between the three rolls. A rotary motion imparted to the rolls causes the tube to revolve, and the canvas and rubber cover are wrapped on in a few seconds. This method has the advantage of consuming very little time, but unfortunately, it is not applicable to the construction of best-quality hose, which are made up by hand with the assistance of small rollers having a concave face. The rollers are run up and down the hose and serve to press each ply of frictioned canvas onto the next.

Before going to the vulcanizer the hose is wrapped with cloth. First, a long strip is wrapped lengthwise on the hose, and over this a narrow strip is wrapped spirally. This is done very rapidly by causing the hose to revolve in roller bearings while the narrow strip of cloth is held under tension and guided by hand. The operation requires only a few minutes.

**3. Vulcanizing.**—The vulcanizer consists of a long cylinder provided with steam and drip connections, and a pressure gauge. The pressure and time necessary for vulcanization depend upon the composition of the rubber compound, the thickness, and the use for which the hose is intended. After vulcanization the wrapping cloth is stripped off, and the hose is removed from the mandrel by means of compressed air, in the same way that the tube was put on. The couplings are now put on and the hose is ready for shipment.

**4. Cotton Rubber-lined Hose.**—In the manufacture of woven cotton hose with rubber lining, the tube is made in the usual way and partially vulcanized, in order that it may develop sufficient strength to be drawn through the cover. A long slender rod is passed through the cover, carrying with it a stout cord. This cord is attached to the end of the rubber tube, and the rod is withdrawn. The cord is now drawn through the cover, bringing the tube with it, the tube having been coated with rubber cement. The hose is now filled with steam under pressure, which expands the tube, thus forcing the cement well into the meshes of the woven cover, and at the same time vulcanizes the rubber.

**5. Braided Hose with Rubber Tube and Cover.**—A form of braided hose which is claimed to have, and appears to have, decided merit, is made as follows:

The rubber tube passes first through a bath of cement and then to the braiding machine, where the first ply of fabric is braided over the fresh cement. This operation is repeated until the desired number of plies have been formed, when the rubber cover is put on and the hose is vulcanized in a mold. While being vulcanized the hose is subjected to air pressure from within, which forces the rubber well into the meshes of the loosely braided fabric.

## RUBBER BELTING

Duck for rubber belting is passed over steam-heated rolls to remove the moisture, and frictioned as described in connection with the manufacture of rubber hose.

The frictioned duck is cut lengthwise into strips, the width of which depends not only upon the size of belt, but also upon the method of manufacture, which is not the same in all factories. These strips are cut by passing the canvas over a drum against which knives are held at points necessary to produce the desired widths.

One method is to make the inner plies of the belt with strips which are equal in width to that of the belt. These strips, stacked one above the other, are placed in the center of a strip of double the width, and in this position they are drawn through an opening with flared edges which folds the bottom strip over the top strips and forms a butt joint on the top face of the belt. The belt then passes between rolls which press the plies firmly together and at the same time lay and press a narrow strip of rubber over the joint. When the belt is to have a rubber cover, as is usually the case, this is calendered onto the outside ply or layer of the canvas before it is put on the belt. Some of the most expensive belts, however, are made without a rubber cover.

Another method is to cut each strip of canvas twice as wide as the belt. The first

strip is folded upon itself, as described above, so that its edges form a butt joint. This folded strip is placed with its joint down upon the next strip, which is in turn folded to form a butt joint on the back of the first strip. In this way, the belt is built up with the desired number of plies, the last joint being covered with a narrow strip of rubber, which is rolled flush with the surface. The belt is now ready to be vulcanized.

In this process there are two steps. First, the closely coiled belt is wrapped so that only its edges are exposed, and in this condition it is put in the vulcanizer. After the edges have been vulcanized the belt is stretched and held under heavy pressure between the steam-heated faces of a long hydraulic press. This drives the friction into the pores of the duck and vulcanizes the belt throughout.

As regards the advantage of using a high-grade rubber cover for belting, the consensus of opinion seems to be that the expense thus incurred, except in the case of conveyor belting, had better be devoted to increasing the quality of friction between the plies of canvas.

## MECHANICAL RUBBER GOODS

The term "rubber," as commonly employed, does not refer to the commercially pure gum, but to a vulcanized compound as already described, which consists of gum, mineral matter or pigments and sulphur, mixed in various proportions, according to the purpose for which it is intended. Mineral matter or the so-called fillers serve a very useful purpose, both in cheapening the product and in adding certain desirable properties which could not otherwise be obtained. Their presence, therefore, should not be looked upon as an adulteration.

There is a limited demand for pure gum by the medical profession and a very considerable amount is used in the manufacture of stationery bands, elastic thread, etc., but the amount of rubber thus consumed is insignificant as compared with the enormous quantity used in the manufacture of mechanical rubber goods, such as automobile tires, hose, packing, and footwear. A properly vulcanized compound of high-grade rubber which is suitable for the best hose and packing, may be stretched to about seven times its original length and has a tensile strength of about 2,000 pounds per square inch.

The properties that are desirable in rubber depend in a great measure upon the use for which it is intended. For example, rubber intended for steam hose or steam packing should be of a composition to withstand high temperatures, while rubber for the tread of an automobile tire should offer great resistance to abrasion.

The real value of rubber in any case depends upon the length of time that it will retain those properties which are desirable, and it is a matter of common observation that rubber often deteriorates less rapidly when in use than when lying idle. Deterioration, as indicated by loss of strength and elasticity, is considered to be the result of oxidation, which action is accelerated by heat and very greatly by sunlight. Other things being equal, the better grades of rubber possess greater strength and elasticity, and may be stretched to a greater extent than the poorer grades, and they also deteriorate less rapidly. The physical properties of rubber, however, are subject to variation within wide limits, depending upon the proportion of gum present, the materials used as fillers, and the extent of vulcanization.

## PHYSICAL TESTING OF RUBBER

Rubber testing in the present stage of its development is not susceptible of very great refinement as regards measurement. The nature of the material is such that refinement seems of less importance than uniformity of methods, which is absolutely essential where the work of different laboratories is to be compared.

**Tension Test.**—Tension tests in various forms are used to determine the more important physical properties, such as tensile strength, ultimate elongation, elasticity, and reduction in tension when stretched to a definite elongation.

**Recovery.**—Recovery as applied to rubber is in a way synonymous with elasticity, and is measured by the extent to which the material returns to its original length after having been stretched. The term "set," as commonly employed, refers to the extension remaining after a specified interval of rest following a specified elongation for a given period of time.

**Friction.**—In the case of such materials as rubber hose and rubber belting, which are built up with layers of duck cemented or frictioned together with rubber, it is customary to determine the friction or adhesion between the plies of duck as well as the quality of rubber. It is also usual to subject hose (particularly fire hose and air hose) to a hydraulic pressure test, in order to detect any imperfections in materials or workmanship.

**Steam Pressure.**—An important test in the case of steam hose consists in passing steam at about 50 pounds pressure through a short length of the hose in order to determine if the rubber is of suitable composition to withstand the effects of service conditions. This test usually lasts for about six days, the steam being turned off at night to allow the rubber to cool. A decided hardening or softening of the rubber, or a large decrease in the value of friction, as a result of steaming, is an indication of inferior quality.

**Packing.**—No absolutely reliable test (other than an actual service test) has been devised for rubber steam packing, but in many cases valuable information may be obtained by clamping a piece of the packing between metal plates and subjecting it to the action of steam at a pressure equal to or slightly above that under which it is to be used. A more satisfactory method is to clamp the packing in the form of a gasket between pipe flanges and apply the desired steam pressure from within. The test should last several days, the steam being turned off at night to see if the joint has a tendency to leak as a result of the cooling effect. This, however, practically constitutes a service test.

**Tires.**—The testing of tires, or rather the materials used in their construction, is done almost exclusively by manufacturers. Manifestly it would be too expensive for the consumer, or even the dealer, to sacrifice whole tires for the purpose of securing test pieces.

The tests which have been outlined above will, in the majority of cases, enable one to form a fairly accurate judgment as to the quality of rubber.

**Tension Test.**—When the material is made up with layers of fabric, as in the case of rubber hose, the first step in preparing specimens for the tension test is to separate the rubber from the fabric. Unless the frictioning is very poor, this will necessitate the use of a solvent. If there is more than one layer of fabric, the easiest way is to remove the first layer along with the rubber. The rubber is then separated from the adjoining layer of fabric by means of gasoline blown from a wash bottle. Narrow strips are more easily handled than larger pieces, and there is less danger of injuring the rubber. The rubber should be allowed to rest for several hours in order that it may recover from the stretching it has received and that the gasoline may thoroughly evaporate.

**Test Piece.**—The central portion of the test piece cut with a metal die is straight for a distance of 2 inches, and the ends are enlarged to prevent tearing in the grips of the testing machine. The width of the contracted section is usually made either one-fourth inch or one-half inch. It is impossible to obtain satisfactory specimens one-half inch wide from hose of small diameter.

Parallel lines 2 inches apart are placed on the specimens, and by means of these gauge marks elongation and permanent extension are measured. A stamp consisting of parallel steel blades enables one to mark very fine lines with ink, without cutting the rubber, and in this way much time is saved and all chance of error eliminated.

**Influence of Speed on Tensile Strength and Elongation.**—The speed at which rubber is stretched probably affects the results to a less extent than is often supposed, though doubtless different rubbers are not equally affected.

**Influence of Temperature on Strength, Elongation, and Recovery.**—It is generally recognized that the physical properties of rubber are affected by changes in temperature, though, of course, to a less extent after vulcanization than before.

The results of tests at 50°, 70° and 90° F., in a room maintained at the specified temperature for three hours before the tests were made. It was observed that the rubbers were not all affected to the same extent by equal differences in temperature, but there was a marked tendency in each case toward decreased strength, decreased set (increased elasticity), and increased elongation as the temperature is raised. It was noted that in nearly every case, greater differences were secured between 50° and 70° than between 70° and 90°.

The set in each case was measured after one minute stretch and one minute rest, Of five specimens, Nos. 1 and 2 were stretched 350 per cent, Nos. 3 and 4, 300 per cent. and No. 6, 250 per cent.

TABLE 1

SHOWING STRENGTH AND ELONGATION OF RUBBER WHEN STRETCHED AT THE RATE OF 30 AND 120 INCHES PER MINUTE

[Gauge length = 2 inches.]

| Rubber No. | 2 | | 3 | | 4 | | 5 | | 6 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Speed in Inches per Minute | 30 | 120 | 30 | 120 | 30 | 120 | 30 | 120 | 30 | 120 |
| Tensile strength (pounds per square inch) . . | 1,740 | 1,690 | 990 | 1,100 | 1,710 | 1,790 | 750 | 920 | 930 | 1,030 |
| Ultimate elongation (per cent) | 665 | 670 | 510 | 530 | 460 | 460 | 430 | 430 | 375 | 380 |

These results would indicate that elongation is not appreciably affected by speed, and that for the lower-grade rubbers greater tensile strength is secured at high speed.

**Influence of Cross Section on Tensile Strength and Elongation.**—Tensile strength and ultimate elongation are theoretically independent of sectional area, but as in other materials there is a tendency for small test pieces to develop higher unit values than large ones. Complete data on this subject is not at hand, but it is thought that test pieces one-fourth inch and one-half inch wide will show but little difference in unit strength and elongation, provided the surface is uniform and the wider specimens are sufficiently enlarged at the ends to prevent tearing in the grips.

**Influence of the Direction in which Specimens are Cut on Strength, Elongation, and Recovery.**—The tensile properties of sheet rubber are not the same in all directions. Specimens cut longitudinally or in the direction in which the rubber has been rolled through the calender show greater strength and (at least for the better grades of rubber) less elongation than specimens cut transversely or across the sheet. The recovery, however, is greater in the transverse direction.

TABLE 2

SHOWING THE RELATIVE STRENGTH, ELONGATION, AND RECOVERY OF RUBBER WHEN TESTED IN THE LONGITUDINAL AND TRANSVERSE DIRECTIONS

| Rubber No. | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Tensile strength[1] (pounds per square inch): | | | | | | |
| Longitudinal. . . . . . . . . . . . . . . . . . . . . . . . | 2,730 | 2,070 | 1,200 | 1,850 | 690 | 880 |
| Transverse. . . . . . . . . . . . . . . . . . . . . . . . . | 2,575 | 2,030 | 1,260 | 1,700 | 510 | 690 |
| Ultimate elongation (per cent): | | | | | | |
| Longitudinal. . . . . . . . . . . . . . . . . . . . . . . . | 630 | 640 | 480 | 410 | 320 | 315 |
| Transverse. . . . . . . . . . . . . . . . . . . . . . . . . | 640 | 670 | 555 | 460 | 280 | 315 |
| Set[1] after 300 per cent elongation for 1 minute with 1 minute rest (per cent): | | | | | | |
| Longitudinal. . . . . . . . . . . . . . . . . . . . . . . . | 11.2 | 6.0 | 22.1 | 34.0 | 27.5 | 34.3 |
| Transverse. . . . . . . . . . . . . . . . . . . . . . . . . | 7.3 | 5.0 | 16.3 | 24.0 | 25.0 | 25.9 |

[1] The set and tensile strength were determined with different test pieces.

**Influence of Previous Stretching on Strength, Elongation, and Recovery.**—Previous stretching seems not only to increase the ultimate elongation, as is generally known, but also the tensile strength, at least in the case of high-grade compounds.

Table 3 gives the tensile strength and ultimate elongation obtained in testing six samples of rubber, first, with a single stretch, and, second, by repeated stretching, beginning with 200 per cent and increasing each stretch by 100 per cent until failure.

The recovery after a definite elongation is usually greater if the rubber has been previously stretched than if determined in the usual way. This is illustrated by the results shown in Table 4, in which the columns marked "Repeated stretch" show the set after repeated stretching, beginning with 100 per cent and increasing 100 per cent for each subsequent stretch. The results in columns marked "Single stretch" were obtained in the usual way, each specimen being stretched but once. In each case, the set was measured from the original gauge marks, after one minute stretch and one minute rest, the tabulated results being the average of a number of observations.

TABLE 3

THE INFLUENCE OF REPEATED STRETCHING ON TENSILE STRENGTH AND ULTIMATE ELONGATION

| Rubber No. | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Tensile strength (pounds per square inch): | | | | | | |
| Single stretch | 2,470 | 1,740 | 990 | 1,710 | 750 | 930 |
| Repeated stretch | 2,610 | 1,960 | 1,180 | 1,790 | 790 | 920 |
| Ultimate elongation (per cent): | | | | | | |
| Single stretch | 645 | 665 | 510 | 460 | 430 | 375 |
| Repeated stretch | 765 | 780 | 645 | 555 | 440 | 465 |

TABLE 4

THE INFLUENCE OF REPEATED STRETCHING ON THE RECOVERY OF RUBBER

| No. | Method of Testing | Set After Being Stretched | | | | |
|---|---|---|---|---|---|---|
| | | 100 % | 200 % | 300 % | 400 % | 500 % |
| 1 | Repeated stretch | 1.0 | 4.5 | 9.5 | 16.0 | 25.0 |
| | Single stretch | ... | .... | 11.7 | 19.8 | 29.0 |
| 2 | Repeated stretch | 1.8 | 4.0 | 7.7 | 13.7 | 21.2 |
| | Single stretch | ... | .... | 8.0 | 14.7 | 21.5 |
| 3 | Repeated stretch | 3.7 | 9.0 | 17.7 | 27.0 | 37.0 |
| | Single stretch | ... | .... | 21.7 | 34.0 | 47.0 |
| 4 | Repeated stretch | 4.0 | 12.3 | 28.7 | 48.7 | .... |
| | Single stretch | ... | 14.3 | 33.0 | 56.0 | .... |
| 5 | Repeated stretch | 8.1 | 19.4 | 34.0 | .... | .... |
| | Single stretch | ... | 19.3 | 33.0 | .... | .... |
| 6 | Repeated stretch | 4.3 | 16.3 | 34.0 | .... | .... |
| | Single stretch | ... | 17.0 | 35.3 | .... | .... |

It will be noted that the effect of previous stretching is very marked in the case of Nos. 1, 3, and 4; that it is very slight in the case of Nos. 2 and 6; and that in the case of No. 5 the set is slightly increased by previous stretching.

**Influence of the Form of Test Specimen on the Results of Tension Tests.**—There is a wide difference of opinion in regard to the relative merits of the straight and ring-

shaped test specimen. The ring, which is highly recommended by some, undoubtedly possesses certain advantages as regards convenience in testing, and uniform results may be obtained by this method.

Ring specimens, however, do not show the full tensile strength of rubber, on account of the uneven distribution of stress over the cross section. This fact is evident from a simple analysis, and may be verified by comparative tests with straight and ring shaped test pieces, provided the straight test pieces are sufficiently enlarged at the ends to prevent failure in the grips, and provided further that the change in width is not made too abruptly.

**Friction Test.**—The "friction" or adhesion between the plies of canvas on rubber hose and between the canvas and the rubber tube and cover, is of great importance;

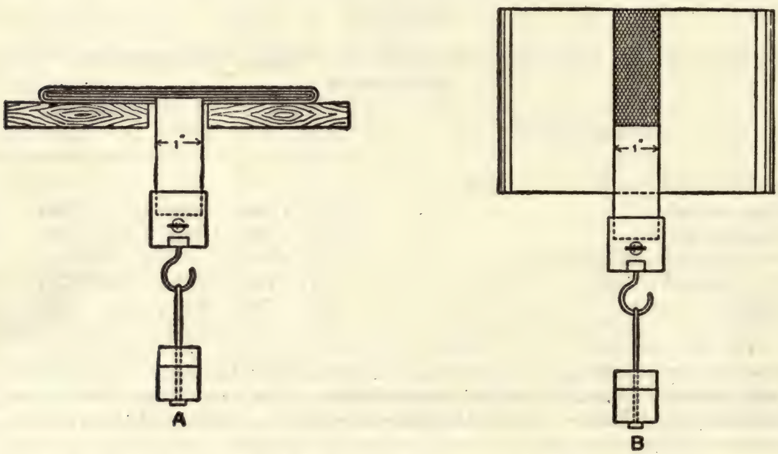



FIG. 2.—TWO METHODS OF TESTING THE "FRICTION" OF RUBBER BELTING.

in fact, the life of hose depends in great measure upon the efficiency of this adhesion. The same is true and to an even greater extent in the case of rubber belting.

The friction of "plied" hose is determined in the following manner: In preparing test pieces, a short length of hose is pressed tightly over a slightly tapered mandrel. The mandrel is put in a lathe, and 1-inch rings are cut with a pointed knife. Beginning at the lap a short length of canvas is separated and the ring is pressed snugly over a mandrel which is free to revolve in roller bearings. The rate at which the canvas strips under the action of a specified weight suspended from its detached end is taken as a measure of the friction.

The "friction" of rubber-lined fire hose is usually determined as follows: A 1-inch strip is cut and a portion of the tube separated from the jacket. The detached end of the jacket is clamped in a stationary grip and the weight is suspended from the rubber tube.

The "friction" between the plies of duck in rubber belting is sometimes measured in the same way (Fig. 2, B), but some prefer to apply the load in a direction at right angles to the plane of separation, as in the case of "plied" hose. This is done by cutting the belt about halfway through along parallel lines 1 inch apart. The belt rests on horizontal supports just outside of the strip which has been cut, and the weight is suspended from the detached end of the duck (Fig. 2, A). It is found that for a given weight the rate of stripping is decidedly greater by the former method than by the latter.

Table 6 gives comparative results obtained by the two methods in the case of a six-ply belt.

**Hydraulic Pressure Test.**—The pressure test as usually made consists simply in subjecting a short length of the hose to water pressure created by a force pump of any

convenient type. When testing a full length of hose, or even a short length of large diameter, a pet cock should be provided to release the air as the hose is being filled.

TABLE 6

SHOWING COMPARATIVE VALUES OF "FRICTION" BY DIFFERENT METHODS

[Inches stripped per minute.]

| Weight (Pounds) | 12 | 15 | 18 | 21 |
|---|---|---|---|---|
| First ply: | | | | |
| Tested as in Fig. 2, B | 0.08 | 0.26 | 1.26 | 3.56 |
| Tested as in Fig. 2, A | .... | .... | .... | 0.11 |
| Second ply: | | | | |
| Tested as in Fig. 2, B | 0.07 | 0.48 | 2.18 | 7.65 |
| Tested as in Fig. 2, A | .... | .... | .... | 0.15 |
| Third ply: | | | | |
| Tested as in Fig. 2, B | 0.04 | 0.32 | 1.33 | 7.00 |
| Tested as in Fig. 2, A | .... | .... | .... | 0.16 |

Requirements of specifications as regards the pressure test vary according to the kinds of hose, but, as a rule, the test is made, not with a view to developing the ultimate strength of the hose, but rather to detect defects in workmanship, which are usually noticeable at a pressure well below that necessary to rupture the hose.

In the case of fire hose, it is usual to specify a certain pressure when the hose is lying straight or when bent to the arc of a circle of given radius; and the hose must stand a specified pressure when doubled upon itself. It must not show excessive expansion, elongation, or twist under pressure, and the twist must be in a direction tending to tighten the couplings.

## THE CHEMISTRY OF RUBBER

Although rubber has been extensively used for a number of years, it is only recently that we have known very much about its chemical nature. The synthesis of rubber shows that it belongs with the terpenes, having the formula of $(C_{10}H_{16})_n$, but so far all attempts to show the actual size of this molecule have been unsuccessful. The synthesis is accomplished by the polymerization of the simple terpene, isoprene, which has the formula $C_5H_8$. Additional proof of the correctness of the above formula is obtained by means of the various addition products which have been formed, such as the tetrabromide, nitrosite, ozonide, etc. These latter show that in the rubber molecule, each group of $C_{10}H_{16}$ is capable of combining with two atoms of sulphur. It is this adding of sulphur during the process of vulcanization which transforms the crude, sticky gum into a tough, elastic material.

The crude rubbers, however, contain other substances than the pure rubber just mentioned; they contain varying proportions of proteids, resins, hydrocarbons, etc.

The mechanical impurities and water-soluble constituents are removed by washing. The resins remain behind and form one impurity which must be determined by chemical analysis. The amount and character of these resins are of great assistance in determining the nature of the rubber used in compounding. In some cases the percentage of resins is exceptionally high and then the crude rubbers must be subjected to a deresinizing process before they can be used.

The acetone extraction for the purpose of determining the quantity of such resins is made by taking a weighed sample of the finely ground material and extracting it with acetone for a period of from 8 to 15 hours. The acetone is removed by distillation, the residue weighed, and the latter, consisting of the rubber resins, subjected to a very careful examination.

If the extraction is made on a vulcanized compound, the acetone also extracts the

free sulphur and any mineral oils or waxes that may have been used. The free sulphur can be readily determined by any of the methods given in the test books, and the amount so determined must be deducted from the total extract. This gives a corrected figure called "organic extract" or, sometimes, simply "corrected acetone extract." For the best grades of Para rubber, this figure should not exceed 5 per cent of the rubber present. A higher percentage of resins would indicate the presence of other rubbers than Para, while the presence of mineral oil indicates the possibility of reclaimed rubber having been used, inasmuch as practically all the reclaimed rubbers are compounded with more or less mineral oil to make them work easier.

The acetone extraction is one of the most promising tests for the examination of rubber goods.

The process of vulcanization consists simply in the chemical combination of sulphur and rubber. Varying amounts of sulphur, depending upon the nature of the crude gum as well as upon the properties desired in the finished product, are added to the compound, and, after heating, varying amounts of the sulphur will be found to have combined chemically with the rubber, giving thus a new chemical compound with new and desirable properties that are not possessed by the crude material.

It is often desirable to limit the amount of sulphur in a compound, and this calls for a method of determining the total amount of sulphur present.

In addition to the sulphur combined with the rubber, and the free sulphur already mentioned, sulphur may be present in the mineral fillers. Barytes is one such compound, and it is permitted in practically all compounds where the amount of sulphur is specified. Sublimed lead (largely a basic sulphate of lead, of varying composition) does not yet fulfil the conditions just mentioned, but it is quite probable that we shall soon be able to determine it accurately, and it will then be merely a question of deciding whether it is a desirable filler in high-grade compounds.

## SECTION 7

# IRON AND STEEL CASTINGS

## FOUNDRY PIG IRON

Pig iron is the metal reduced from iron ores in a blast furnace. It is the crudest form of iron in the market and seldom or never used without remelting. It is often referred to as an impure iron because there are always contained in the pig metal certain elements such as carbon, silicon, manganese, sulphur, phosphorus, etc. The effect of each of these when combined with iron is substantially as follows:

**Carbon.**—This element is always present in pig iron either as free graphite in which thin flakes of graphite are mechanically present between the crystals of iron, as in soft gray iron; or it may be chemically combined as in white iron, which is much harder. The quantity of carbon in cast iron is largely dependent upon the temperature of the furnace. It has been commonly understood that the highest amount of carbon that can be taken up by pure iron is 4.50%, and at 1100° C. (2012° F.) this percentage is correct, but E. Adamson found on raising the temperature to 2200° C. (4992° F.), 9.50% carbon could be absorbed. He further states that iron containing 4.50% carbon when cooled down under normal conditions made white iron; but with the higher percentage it was impossible to secure a white iron, because a certain amount of graphite separated out and made it gray or mottled.

An important point is the time during which the iron is left in contact with the hot coke in a foundry cupola, also the temperature of melting, as this latter decides the total amount of carbon taken up. On remelting pig or cast iron, the primary condition of the carbon is important in influencing the grade and strength of the material produced. The quicker the cooling, the more closely compacted the form of the carbon, and therefore the greater the strength and durability of the metal.

**Foundry Irons.**—The total carbon in No. 1 pig iron is about 3.60%, of which 0.10% will be combined.

In No. 2 pig iron the total carbon is about 3.50%, of which about 0.20% will be combined.

In No. 3 pig iron the total carbon is about 4.00%, of which about 1.00% will be combined.

In No. 4 pig iron the total carbon is about 4.00%, of which about 2.00% will be combined.

**Silicon.**—This element diminishes the power of carbon to unite with iron, and tends to cause the separation of carbon as graphite, especially when the metal is slowly cooled from a white heat. It increases the fluidity of cast iron, while decreasing its strength. As compared with carbon, the silicide FeSi dissolves readily in the iron, and, like the carbide, hardens the metal, but to a much less extent than the carbide, approximately 5% silicon being the same as 1% carbon, so that if silicon be added to iron, there being no other constituents present, the tendency is to give a hard metal, but silicon has an indirect influence which is of much greater importance in that it expels the carbon from combination and throws it into the graphitic form.

Gray iron castings, having moderately large crystals, therefore, rich in graphitic carbon, are commonly those of high silicon content, cast in sand, and slowly cooled. Silicon in moderate quantity added to cast iron diminishes the hardness, increases the tensile strength, increases the resistance to crushing, increases the density, prevents the formation of blow holes, and diminishes the shrinkage.

Shrinkage appears to closely follow the hardness of cast iron, and as both hardness and shrinkage depend on the proportion of combined carbon they may be regulated by the addition of silicon.

Silicon in No. 1 pig iron will average 2.50% and upwards. No. 2 pig iron will range between 2.25% and 2.75%, averaging about 2.50%. No. 3 pig iron will range between 0.75% and 200%, averaging about 1.60%. No. 4 pig iron will range between 0.80% and 2.00%, averaging about 1.60%.

**Silicon Pig.**—This alloy when made in the blast furnace is from highly silicious ores, at a temperature much higher than for ordinary foundry irons; the blast must be much stronger to quickly burn the excess of fuel supplied. Silicon is not reduced by carbonic oxide or incandescent carbon alone except in the presence of molten iron, with which it readily enters into combination, the resulting product being a silicon pig, containing from 3 to 10% silicon, depending upon the quality of the ores. According to Turner the maximum resistance to tension, bending, and crushing pig iron is attained by proportions of silicon varying from 1.5 to 3%. Pig iron containing 2 to 3% of silicon is softer than other irons, hence silicon iron is used in admixture with other brands of pig iron in the foundry to produce soft gray castings.

**Manganese.**—This element is always present in pig iron; it increases the power of carbon to combine chemically with iron at high temperatures, the effect of which is to change the characteristic coarse grain of gray iron to a finer grain; the percentage of combined carbon will be greater, the iron will be much harder, and if the percentage of manganese be sufficiently increased a white iron will result. Manganese is more readily oxidized than is iron, it therefore unites with oxygen in the liquid iron and acts as a deoxidizer, it also counteracts the bad effects of sulphur, thus preventing red shortness, but it does not prevent the cold shortness due to phosphorus. The compounds of iron and manganese are limited in composition as shown by the crystalline forms so characteristic of spiegeleisen, but with increase in manganese the crystals are greatly modified, they are much smaller and less brilliant. Sulphur present as iron sulphide in pig iron will undergo decomposition by manganese and a manganese sulphide formed, thus liberating the iron which was in combination with the sulphur. The bad effects of sulphur, which are to render iron red short hard and brittle, as also its power of reducing oxide of iron, are thus counteracted by the manganese sulphide which, not being as soluble in iron as in iron sulphide, passes into the slag.

**Spiegeleisen.**—Manganese combines with iron in nearly all proportions, the two best known alloys are spiegeleisen and ferro-manganese. This alloy much used in steel making is not used in foundry practice, except in special cases. Foundry irons do not often contain more than 4.0% total carbon; spiegeleisen will have 5.0 to 6.0% total carbon; the manganese content will approximate 15.0% in combination with 5.0% carbon up to 30.0% with 6.0% carbon.

**Ferromanganese.**—This alloy differs from spiegeleisen in its having a much higher percentage of manganese, of which the lower limit is 25 to 30%; its higher limit extends to 85 or, in some instances, to 90%. Commercial needs cover nearly all proportions up to 80% manganese, in combination with 5 to 7% of iron. An alloy with 40% manganese will have a carbon content of 4.5 to 5.0%, which is more carbon than ordinary pig iron contains. This higher carbon content over that of ordinary pig iron is due to the influence of the manganese present which increases the power of the iron to absorb more carbon.

**Silicon-spiegel.**—Silicon is always present in ferromanganese as it is a constant constituent in pig iron; it has a marked effect upon steel in promoting the solubility of gases and by reducing a part of the iron oxide. In silicon-spiegel, which is an alloy of iron, manganese, silicon and carbon, notwithstanding the presence of a large amount of manganese, the silicon prevents carbonization taking place by expelling the carbon from combination and throwing it into the graphitic form. This alloy is seldom used in the foundry, but it is useful in the manufacture of steel and steel castings.

**Oxygen and Manganese.**—Manganese prevents the oxidation of iron when in the molten state, but as manganese is more oxidizable than iron, the more readily does it combine with oxygen, passing into the slag with silica, thus protecting the other constituents in the iron from oxidation. Manganese is reduced from its oxide at a white heat, while silica is unaffected, showing that manganese has a lower affinity for oxygen than silicon.

**Sulphur.**—This element is always present in pig iron; its tendency is to make the

metal hard, brittle, and weak. The indirect action of sulphur is exactly opposite to that of silicon; that is, it tends to retain the carbon in the combined condition. When sulphur is present in pig iron it lowers the temperature at which solidification begins, and as the cooling progresses the iron sulphide separates and forms layers or films between the crystals, preventing them from coalescing and from breaking up into ferrite and graphite. These sulphide films are very thin, and a very small quantity of sulphur thus present will make iron brittle. Dr. Moldenke states that, taking the three arbitrary divisions of gray iron castings, the light, medium and the heavy, a limit should be placed in the sulphur at 0.08, 0.10, 0.12 respectively.

Sulphur has a well-known influence in increasing the depth of " chill " in solidifying cast iron against a metal wall, that is the thickness of metal free from graphitic carbon produced by the cooling action of that wall. Its other influences are harmful as it increases shrinkage, causes the molten metal to be sluggish and induces unsoundness.

**Phosphorus.**—When present in iron ores occurs chiefly as phosphate of lime; as but little phosphorus is oxidized in the blast furnace, nearly all that contained in the ores finds its way into the pig iron. Phosphorus combines with a carbonless iron to form a phosphide $Fe_3P$, which is soluble in iron up to 1.7%; beyond this, free phosphide separates out and forms an eutectic, and this is the form in which it occurs in cast iron.

The percentage of carbon in pig iron containing much phosphorus is lower than in that containing no phosphorus. Owing to the low melting point of the phosphide, eutectic iron high in phosphorus is extremely fluid and gives fine castings, but the metal is brittle. For fine castings in which strength is not important 1.50% phosphorus may be employed, the metal will not only be very fluid, but the phosphorus lessens the shrinkage of the castings.

The presence of a large amount of carbon in cast iron is a means of liberating phosphorus held in solution, causing it to pass into an eutectic condition in gray cast iron, even if the metal contains less than the 1.7% phosphorus needed to saturate the iron. Phosphorus has little effect on the condition of the carbon, but it makes the metal harder and diminishes the color of gray iron. When phosphorus does not exceed 1.7% the metal is comparatively strong but an addition of 0.35% reduces the strength. For strong castings the phosphorus should not materially exceed 0.50%. The general influence of phosphorus is to increase the fluidity of iron and thus insure castings accurate as to size, because phosphorus lessens the shrinkage on solidifying, it also produces a sounder casting; but phosphorus in excess of about 1.50% has another influence, and that is to weaken iron, to diminish its hardness, and to render it cold short. As a rule pig irons should not, in a cupola mixture, average more than 1.0% phosphorus for the ordinary run of machinery castings, below 0.50% the iron will not be sufficiently fluid, and with more than 1.50% medium and small castings will be too brittle.

**Foundry Irons.**—Phosphorus in No. 1 pig iron ranges from 0.50 to 1.25%, often higher. No. 2 pig iron ranges from 0.40 to 1.00%. No. 3 pig iron ranges from 0.40 to 0.80%. No. 4 pig iron contains about 0.40%, or less.

United States Navy specifications require 0.50 to 0.80% in Nos. 1 and 2 pig irons, and 0.50 to 0.90% in No. 3 iron. For No. 4 charcoal iron the maximum phosphorus is 0.30%.

**Grading Pig Iron.**—Pig iron is sold in the market in five grades, Nos. 1, 2, 3, 4 and 5. Besides there are special grades established recently but used extensively, namely: Low phosphorous and sulphur iron used in the open-hearth and Bessemer process. Silicized iron containing 4 to 7% of silicon is also made to soften other irons and to make them run liquid.

The following chemical analysis and physical characteristics of Pennsylvania pig irons are by John Hartman.

## GRADES OF PIG IRON

### ANALYSIS OF STANDARD

#### No. 1 Pig Iron.

| | |
|---|---|
| Iron | 92.37% |
| Graphitic Carbon | 3.52 |
| Combined Carbon | 0.13 |
| Silicon | 2.44 |
| Phosphorus | 1.25 |
| Sulphur | 0.02 |
| Manganese | 0.28 |

*Gray.* A large, dark, open grain iron, softest of all the numbers and used exclusively in the foundry. Tensile strength, low. Elastic limit, low. Fracture, rough. Turns soft and tough.

#### No. 2 Pig Iron

| | |
|---|---|
| Iron | 92.31% |
| Graphitic Carbon | 2.99 |
| Combined Carbon | 0.37 |
| Silicon | 2.52 |
| Phosphorus | 1.08 |
| Sulphur | 0.02 |
| Manganese | 0.72 |

*Gray.* A mixed large and small dark grain, harder than No. 1 iron and used exclusively in the foundry. Tensile strength and elastic limit higher than No. 1. Fracture, less rough than No. 1. Turns harder, less tough and more brittle than No. 1.

#### No. 3 Pig Iron

| | |
|---|---|
| Iron | 94.66% |
| Graphitic Carbon | 2.50 |
| Combined Carbon | 1.52 |
| Silicon | 0.72 |
| Phosphorus | 0.26 |
| Sulphur | Trace |
| Manganese | 0.34 |

*Gray.* Small, gray, close grain, harder than No. 2 iron, used either in the rolling mill or foundry. Tensile strength and elastic limit higher than No. 2. Turns harder, less tough and more brittle than No. 2.

#### No. 4 Pig Iron

| | A | B |
|---|---|---|
| Iron | 94.48% | 94.08% |
| Graphitic Carbon | 2.02 | 2.02 |
| Combined Carbon | 1.98 | 1.43 |
| Silicon | 0.56 | 0.92 |
| Phosphorus | 0.19 | 0.04 |
| Sulphur | 0.08 | 0.04 |
| Manganese | 0.67 | 2.02 |

*Mottled.* White background, dotted closely with small black spots of graphitic carbon, little or no grain. Used exclusively in the rolling mill. Tensile strength and elastic limit lower than No. 3. Turns with difficulty, less tough and more brittle than No. 3. The manganese in this (B) pig iron replaces part of the combined carbon, making the iron harder and closing the grain notwithstanding the lower combined carbon.

#### No. 5 Pig Iron

| | |
|---|---|
| Iron | 94.68% |
| Combined Carbon | 3.83 |
| Silicon | 0.41 |
| Phosphorus | 0.04 |
| Sulphur | 0.02 |
| Manganese | 0.98 |

*White.* Smooth, white fracture, no grain, used exclusively in the rolling mill. Tensile strength and elastic limit much lower than No. 4. Too hard to turn and more brittle than No. 4.

| | Per Cent Combined Carbon |
|---|---|
| Malleable iron contains | 0.25 |
| Steely iron contains | 0.35 |
| Steel contains | 0.50 |
| Hard steel contains | 1 to 1.50 |

Taking the sum of the graphitic and combined carbon in each quality of pig iron they are practically the same, the softness of pig iron is dependent on the amount of graphitic carbon in it. Separating the iron in the No. 1 pig from the graphitic carbon it is a nearly pure iron embedded in the graphitic carbon, and in the absence of combined carbon, gives it the softness and flexibility that makes it desirable for machinery and other purposes. The grains of iron are crude crystals. When the iron is nearly pure and allowed to cool very slowly, regular octahedral crystals of iron are formed.

No. 1 Pig Iron may be defined as being composed of grains of wrought iron connected together but embedded in graphite.

No. 2 Pig Iron has more combined carbon, which converts the wrought iron into a soft steel harder to the tool working it.

No. 3 Pig Iron has more combined carbon, and the iron portion is a crude steel harder to the tool working it.

Nos. 4 and 5 are virtually crude, high-combined carbon steel. The numbers here given, 1, 2, 3, 4, 5, are the old standard.

If the impurities in pig iron were uniform, which would be the case if there were only one kind of ore and fuel, the proper plan would be to buy iron by chemical analysis on a basis of graphitic and combined carbon, but the impurities so change the character that the eye is found to be the best guide so far in fixing the grade. In running the end of the fingers over a fracture of a pig of iron, if the ends of the grains tear the fingers the iron is strong.

The analysis (B) of No. 4 Pig Iron shows low in combined carbon, but the manganese hardens the iron and changes it from gray to mottled iron.

No. 1 Hot-blast Charcoal Iron

Grand Rivers, Ky.

| | |
|---|---|
| Silicon | 1.955% |
| Sulphur | .029 |
| Phosphorus | .488 |
| Manganese | .213 |
| Graphitic Carbon | 3.310 |
| Combined Carbon | .460 |
| Iron | 93.545 |

The pigs of this iron bend before breaking. The ends of the grain are sharp and tear the fingers. On breaking this iron the pig when it strikes the breaking blocks emits a dull thud like lead. It is an iron of high tensile strength and well adapted for making car wheels. The bending of pigs is not confined to charcoal iron. Coke and anthracite irons do the same when using good stock and running the furnace at the proper temperature.

# FOUNDRY PIG IRON

## NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Grades.**—There shall be four grades of pig iron conforming to the requirements stated below.

3. **Chemical Requirements.**—The chemical requirements shall be as follows:

| Grade | Carbon (Minimum) | Silicon | Sulphur (Maximum) | Phosphorus | Manganese | Remarks |
|---|---|---|---|---|---|---|
| | *Per Ct.* | *Per Cent* | *Per Ct.* | *Per Cent* | *Per Cent* | |
| No. 1. | 3.50 | 2.75 to 3.25 | 0.04 | 0.50 to 0.80 | 0.50 to .90 | |
| No. 2. | 3.25 | 2.00 to 2.50 | .05 | .50 to .80 | .50 to .90 | |
| No. 3. | 3.25 | 1.25 to 1.75 | .06 | .50 to .90 | .50 to .90 | |
| No. 4. | 3.25 | 1.50 to 2.00 | .03 | .30 max. | .75 to 1.25 | Charcoal iron |

4. **Purpose for Which Used.**—Grade 1 is suitable for general foundry purposes. It may be used for either heavy or light castings which are to be machined.

Grade 2 is suitable for marine engine cylinders, turbine casings, and work of similar character.

Grade 3 is suitable for hard, close-grained castings, which are to be machined, where great strength is required. It may also be used with Grades 1 and 2 in varying proportions as the work requires.

Grade 4 is suitable for use with Grades 1, 2, and 3 where castings of great strength or high finish are desired.

5. **Sampling.**—The sample is to be taken as follows:

One pig shall be taken for every 4 tons in the lot, chosen from different locations so as to represent as nearly as possible the average quality of the iron. The pigs selected for sampling shall each be drilled with two $\frac{9}{16}$-inch holes, spaced about $\frac{1}{3}$ the length of pig from each end. The holes shall run from bottom to top of the pig, the drillings of the first $\frac{1}{4}$ inch to be discarded, and the drill to be stopped about $\frac{1}{4}$ inch from the top of the pig. All drillings from the same lot to be thoroughly mixed, and analysis made from this sample; no resampling to be allowed.

6. **Method of Analysis.**—The inspector at the place of manufacture shall forward to the navy-yard requiring the pig iron not less than 6 ounces of the sample, taken and mixed as above, for analyses and recommendation as to acceptance. In case the first analysis shows that the material does not conform to the specifications a check analysis shall be made. The average of these analyses shall be considered final. Analyses shall be made according to the standard method of the American Foundrymen's Association, the gravimetric method being used for determination of sulphur. Each bidder shall state in his proposal the composition of the pig iron he proposes to furnish if awarded the contract.

7. **Penalties.**—Silicon.—For each 0.01 per cent below minimum content specified a penalty of $0.02 per ton to be exacted. If the silicon content is below the specified content by more than 0.10 per cent the pig iron will be rejected.

Sulphur.—For each 0.002 per cent above maximum content specified, a penalty of $0.10 per ton to be exacted. If the sulphur content exceeds the specified content by more than 0.01 per cent, the pig iron will be rejected.

8. **Locality.**—When it becomes necessary for a navy-yard to obtain pig iron from a particular locality to insure the best results in the foundry, the requisition should state whether Northern, Virginia, or Southern iron is desired.

9. **Sow Iron.**—Not more than 12 per cent of sow iron will be allowed, and this must be of size to be easily handled.

## CHEMICAL CHANGES IN THE CUPOLA

The foundry cupola is a melting and not a refining furnace. The chemical changes which take place in it are of secondary importance to results sought by melting and mixing irons to produce a metal having properties suited to the work in hand.

Pig irons contain carbon, silicon, manganese, sulphur, phosphorus, which are chemically combined with the iron, and these must be dissociated before any oxidation be begun. In the combustion zone opposite the tuyeres is a mass of burning coke into which the blast is projected, combustion is quickened, and the heat thus generated melts the charge of pig iron immediately above. As the metal melts it passes down through the combustion zone and accumulates in the hearth below. The falling metal is in small globules or drops, and when these drops pass the tuyeres, where there is always an abundant supply of free oxygen, there must be more or less of oxidizing action upon the iron and its contained elements in solution.

Carbon in foundry irons is mostly in the graphitic state and as such easily oxidized. But any such oxidation is offset by the drops of iron coming in contact with red hot coke and thus taking up additional carbon, so that, instead of diminishing the total carbon, it happens that the iron flowing from the cupola contains quite as much carbon as was present in the pig iron, and possibly more.

Silicon undergoes oxidation during the melting process, it is to be expected, therefore, that the iron as cast will contain less silicon than the pig, because 0.25 to 0.40% will have been burned out of it during the melting of the iron, and proper allowance for this wastage must be allowed for in the charge.

Manganese is more oxidizable than iron, it more readily unites with oxygen and thus retards the oxidation of iron; during the process of cupola melting manganese volatilizes to some extent, but the quantity present in foundry pig iron is never large and its influence in the cupola is not important. Its tendency is, however, to counteract the bad effects of sulphur, and to increase the solvent power for carbon at high temperatures and to prevent the separation of graphite at lower ones. It also assists in making a more fusible slag by the readiness with which it unites with silica.

Sulphur is always present in pig iron. Irons high in silicon are usually low in sulphur; the latter is always present as ferrous sulphide which is readily soluble in molten iron. The tendency of sulphur is to keep the carbon in the combined condition, the effect of which is to make castings hard and brittle. Coke always contains sulphur and during the process of combustion it unites with oxygen forming sulphurous oxide, which passes off with the other products of combustion into the open air. Sulphur in the pig iron as charged is not reduced; during the process of cupola melting, in fact, the iron may take up 0.02 to 0.03% sulphur from the coke; castings from pig irons containing 0.08% sulphur may contain 0.10% sulphur, especially during the first of the heat.

Phosphorus passes through the melting process in the cupola unoxidized; whatever phosphorus is contained in the pig iron as charged will be present in the molten iron flowing from the cupola.

**Foundry Coke.**—An excellent quality of coke for foundry use is such as made in the Connellsville region, Pennsylvania; its characteristics are: steel-gray color, a metallic luster, columnar, very strong, dense, slightly puffed on the surface, burns free under a strong blast, and will support any necessary weight of iron above it, in a cupola, without crushing. Such a coke, after expulsion of moisture, averages about 90.0% fixed carbon, no volatile matter, 10.0% ash; the latter consisting of about 58.0% silica, 35.0% alumina, 2.0% sesquioxide of iron, 1.5% lime, 2.0% sulphur, 1.0% other constituents, such as magnesia, potash, soda, phosphoric acid, etc. The quantity of sulphur in the ash will depend largely upon the quantity of pyrites in the coal before coking. Pyrites is also the probable source of the oxide of lime in ashes; the greater part of the sulphur being expelled by heat during the process of coking, its equivalent of oxygen unites with the iron, with which hydrogen also combines, forming the sesquioxide of iron.

Alumina present in ashes is in the form of a clay or a mixture of the two simple

earths, alumina and silica, generally tinged with iron, it is infusible in the cupola. Silica is decomposed at a red heat by carbon in presence of iron and at white heat by carbon monoxide, CO, a metallic silicide being formed; it plays a very important part in the formation of slags, and fusion is not necessarily required to produce combination. The bases which most frequently occur in slags are lime, magnesia, oxide of iron, potash in small quantity, and alumina.

**Calorific Value of Coke.**—The total heat obtained by the combustion of 1 pound of carbon in oxygen to carbon dioxide $CO_2$, as determined by calorimeter test, varies in a slight degree from 14500 B.t.u., that value may, therefore, be accepted as a fair average. If the coke is 90.0% carbon we have 14500 × 0.9 = 13050 B.t.u. as the total calorific value of 1 pound of coke. A result such as this is never realized in practice, instead of the carbon being burnt to carbon dioxide $CO_2$, yielding 14500 B.t.u., it may be burnt to carbon monoxide CO, the calorific value of which is 4450 B.t.u., approximately one-third of the former. Gases escaping from the cupola show about equal volumes of $CO_2$ and CO, the calorific value of the carbon suffers loss to the extent of: (14500 × .5) + (4450 × .5) = 9475 B.t.u., equivalent to 65% thermal efficiency.

The temperature at the melting zone in the cupola may be estimated thus: For perfect combustion 1 pound of carbon will require 2.67 pounds of oxygen, yielding 3.67 pounds carbon dioxide $CO_2$. In addition there will be 8.94 pounds of nitrogen left after the separation of the oxygen from the air. The specific heat of carbon dioxide $CO_2$ is 0.216, and that of nitrogen 0.244. We have then:

| Products | Pounds | | Specific Heat | | Heat Units |
|---|---|---|---|---|---|
| Carbon dioxide $CO_2$ | 3.67 | × | .216 | = | .794 |
| Nitrogen | 8.94 | × | .244 | = | 2.181 |
| | 12.61 | | | | 2.975 |

heat units absorbed in raising the temperature of the products of combustion of 1 pound of carbon, 1° F. The combined weights of the two products are 12.61 pounds. Then: 2.975 ÷ 12.61 = 0.236, their mean specific heat. Dividing the total heat of combustion of 1 pound of carbon by the heat units absorbed, as above, we have: 14500 ÷ 2.975 = 4874° F.; the highest theoretical temperature attainable by 11.61 pounds of air, the minimum theoretical limit.

This temperature occurs only opposite the tuyeres and at the time of combination. As the carbon dioxide $CO_2$ rises in the cupola it passes through a bed of incandescent coke, some of the gas takes up another equivalent of carbon and carbon monoxide CO is formed. Upon analyzing the gases escaping from the cupola it is found that carbon dioxide $CO_2$ and carbon monoxide CO escape in practically equal volumes. The temperature is greatly affected thereby, and may be estimated per pound of carbon thus:

| Gas | Pounds | | Specific Heat | | Heat Units |
|---|---|---|---|---|---|
| Carbon dioxide $CO_2$ | 1.84 | × | .216 | = | .397 |
| Carbon monoxide CO | 1.17 | × | .243 | = | .284 |
| Nitrogen | 6.71 | × | .244 | = | 1.637 |
| | | | | | 2.318 |

The total heat of 1 pound of carbon burnt:

0.5 lb. burnt to $CO_2$ = 14500 ÷ 2 = 7250

0.5 lb. burnt to CO = 4450 ÷ 2 = 2225

9475

Then: 9475 ÷ 2.318 = 4087° F., about 16% less than in the earlier example.

The heat required to raise 1 pound of iron to its melting point and melt it, and impart sufficient heat to the molten metal to keep it fluid for pouring, is about 625 B.t.u., or 2240 × 625 = 1,400,000 B.t.u., per ton. The melting of iron is always accompanied by the production of slag consisting principally of silica and alumina, each having a higher melting point than iron. The percentage of slag will vary, but we may for the purpose of illustration take the very low limit of 3.5% of the weight of pig iron melted, or 78 pounds of slag per ton. The total heat required to melt 1 pound of slag at furnace temperature approximates 750 B.t.u. Then: 78 × 750 = 58500 B.t.u., to be added to 1,400,000 = 1,458,500 total B.t.u. required per ton of pig iron melted.

In estimating the calorific value of coke, it was assumed to be 90.0% carbon, therefore 14500 × 0.90% = 13050 B.t.u. per pound. There would be required for 2240 pounds of iron 1,458,500 ÷ 13,050 = 111.7 pounds of coke. This corresponds to the melting of 20 pounds of iron per pound of coke. No such rate of melting occurs in any cupola; reference has already been made to the fact that the escaping gases consist in practically equal volumes of $CO_2$ and CO, and that the B.t.u. had been reduced from 14,500 to 9,475 per pound of carbon. We have then 9,475 × 90.0% = 8,527 B.t.u. per pound of coke, and 1,458,500 ÷ 8,527 = 171 pounds of coke per ton of iron melted, or 13 pounds of iron melted per pound of coke, on the carbon basis alone.

**Excess of Air.**—In estimating the calorific value of 1 pound of carbon in which 14,500 B.t.u. were obtained, it was stated that 11.61 pounds of air were used, a much smaller quantity than obtains in practice. Probably no less than 18 pounds of air are blown into the cupola for each pound of coke burnt; this air has to be heated to the temperature of the escaping gases, and one bad feature about it is that the abstraction of heat occurs in the melting zone, thus depriving the furnace of heat which otherwise would be usefully employed in melting iron. This dilution of gases in the cupola reduces its efficiency and is one of the reasons for its lower melting capacity, reducing the ratio of 13 to 1 as given above to 10 to 1, a good working ratio and much better than obtains in many foundries.

**Temperature of Escaping Gases.**—This will vary with each cupola; beginning with the temperature of the melting zone, the gases lose heat in their passage upward through the successive layers of iron and coke, constituting the cupola charge. A reduction in temperature occurs during the inevitable breaking down of carbon dioxide $CO_2$ and the formation of carbon monoxide CO. There is also an excess of air in the cupola which carries with it a temperature corresponding to that of the fuel gases, this excess of air may be anywhere from 50 to 100% of that necessary for combustion. The presence of moisture in the air; in the coke; on the surface of the iron to be melted; the melting of the several constituents which form the slag; the radiation of heat from the cupola itself, all these tend to reduction of temperature of escaping gases, which for a well proportioned cupola may, in the absence of pyrometer test, be reckoned at 1600° F.

**Slag.**—This is a fused compound of silica in combination with lime, or other bases; slag produced in the cupola will vary in composition with the irons being melted. Silicon is easily oxidizable and forms silica. Most pig irons are cast in sand and a certain amount of sand, say 1.0% attaches to the outer surface of the pig; this sand is nearly all silica. Coke consists of about 50.0% ash, and this ash contains about 50.0% silica. When iron is oxidized ferrous oxide is formed, and this oxide combines with silica forming silicate of iron, or slag.

**Flux.**—In order to promote the fusion of non-metallic substances during the process of melting iron in a cupola a flux is employed. For foundry use calcium carbonate $CaCO_3$, or carbonate of lime is commonly used, chiefly as limestone, gray in color, more or less impure, containing clay, sand, and other substances. If procurable, the white marble refuse chips from a stone yard are preferable, on account of their greater purity. When calcium carbonate $CaCO_3$ is heated it yields calcium oxide CaO, or lime, a white amorphous infusible substance, and carbon dioxide $CO_2$, or carbonic acid gas. Pure carbonate of lime $CaO_3$ = 56% lime CaO + 44% carbon dioxide $CO_2$. The carbon dioxide passes off into the open as a gas; the lime passes into the slag.

Limestone should not contain much silica because of its affinity for lime, forming a silicate of lime, which reduces the fluxing value of the limestone and increases the

quantity of slag. When the melting has begun, the molten iron is in an atmosphere containing free oxygen and oxidation of iron takes place; some of the silicon in the iron is also oxidized, and silica is formed. The oxide of iron will combine with the silica, and a silicate of iron or slag is formed. The fluid slag finds its way down through the burning coke and in its course it takes up any ash present in the coke, as well as the sand which adhered to the pig iron, these, and other impurities, combine in a fluid mass which floats upon the molten iron at the bottom of the cupola.

If white marble chips are used, the quantity may be, for reasonably clean pig, about 20 pounds per ton of iron. For ordinary limestone the quantity may be 40 pounds or more to the ton. Much depends upon the purity and cleanliness of the iron and the quantity as well as the quality of the ash from the coke. If the iron is clean, the weight of the slag will be about the same as that of the limestone charged. For each 56 parts of lime that can be put into the slag, 72 parts of iron oxide, or 56 parts of iron will be liberated. Slag from a cupola contains from 5.0 to 8.0% of iron, partly as oxide, and partly in small particles held in mechanical suspension.

**Fluorspar.**—This substance derives its name from its power to effect the liquefaction of earthy substances. It is a combination of 1 part calcium Ca with 2 parts fluorine F, the formula being $CaF_2$. This compound occurs in large quantities in nature in crystallized cubes; it is insoluble in water. If it be strongly heated in contact with silica, the latter takes up the fluorine to form the gas silicon fluoride $SiF_4$, whilst the calcium and oxygen unite to produce lime, which combines with another portion of the silica to form a silicate of lime. The silicate of lime would not easily fuse into a slag by itself, but when clay and oxide of iron are present, a slag is readily produced. It is used in metallurgical operations for the reason that it melts readily into a transparent liquid which does not act upon other substances easily; it serves as a liquid medium in which reactions take place at high temperatures. For foundry use it serves no useful purpose that cannot be had by the use of white marble chips or first quality limestone except perhaps to increase the fluidity of the slag.

## FUEL EFFICIENCY OF THE CUPOLA FURNACE

The heat balance in melting 80,000 pounds of pig iron in a 60-inch cupola is thus given by John Jermain Porter, Trans., Am. Inst. Mining Engrs., 1912. The cupola selected operated under fairly efficient conditions; the data are as follows: Cupola, 60 inches in diameter, 15 feet high to the charging door, with a 9-inch lining. Bed charge, 2,000 pounds of coke and 4,000 pounds of iron. Subsequent charges, 400 pounds of coke and 4,000 pounds of iron. Total number of charges, 20. There was 800 pounds of coke recovered from the drop, hence the total coke burned is 8,800 pounds, or 0.11 pound of coke per pound of iron. Coke contains 90 per cent fixed carbon and 2 per cent of moisture. 300 pounds of kindling wood is used in lighting. 80 pounds of limestone (95 per cent $CaCO_3$) is used per charge, 0.02 pound per pound of iron. Melting loss 4 per cent; distributed thus: Fe, 3.5; Si, 0.25; Mn, 0.25 per cent. Average analysis of top gases: $CO_2$, 15.1; CO, 10.0 per cent. Average temperature of top-gases, 1,600° F. Temperature of air and stock charged 60° F. Dew-point of air, 50° F. The items entering into the total heat balance and their calculation are as follows:

1. **Heat of Combustion of Fuel.**—Total heat evolved = 14,580 × lb. of carbon burned + 7,200 × lb. of wood burned. Hence B.t.u. per pound of iron charged =

$$\frac{8{,}800 \times 0.9 \times 14{,}580 + 300 \times 7{,}200}{80{,}000} = 1{,}470.4$$

2. **Oxidation of Iron to FeO.**—B.t.u. per pound of iron charged = 0.35 × 2,112 = 74.0

3. **Oxidation of Silicon to $SiO_2$.**—B.t.u. per pound of iron charged = 0.0025 × 12,600 = 31.5

4. **Oxidation of Manganese to MnO.**—B.t.u. per pound of iron charged = 0.0025 × 2,975 = 7.4

5. **Sensible Heat in Coke.**—B.t.u. per pound of iron charged = 0.11 × 60 × 0.16 = 1.1

6. **Sensible Heat in Iron.**—B.t.u. per pound of iron charged = 1 × 60 × 0.12 = 7.2

7. **Sensible Heat in Limestone.**—B.t.u. per pound of iron charged = $0.02 \times 60 \times 0.21 = 0.252$

8. **Sensible Heat in Blast.**—From the gas analysis, 9 pounds of air is used per pound of carbon burned, hence B.t.u. per pound of iron charged = $0.11 \times 0.9 \times 9 \times 60 \times 0.235 = 12.6$.

9. **Heat of Formation of Slag.**—This is a matter of some uncertainty but is of minor importance. The heat of formation of $CaO + SiO_2$ is 278 B.t.u. per pound, and of $FeO + SiO_2$ 121 B.t.u. per pound, and if we assume that the slag consists of equal parts of each, and that 0.06 pound of slag is made per pound of iron, the heat of the formation of the slag is in B.t.u. per pound of iron charged $0.06 \times 200 = 12.0$.

1a. **Heat in Molten Iron.**—B.t.u. per pound of iron charged = $0.96 \times 450 = 432.0$.

2a. **Heat in Molten Slag.**—B.t.u. per pound of slag = $1 \times (t \times (0.17 + 0.00004t)$ + latent heat of fusion + $(t' - t) \times 0.35)$, where $t$ = the melting point of the slag or say, 2,000° F., and $t'$ = the temperature at which it issues from the cupola or, say, 2,250° F. Hence B.t.u. per pound of iron charged = $0.06\ (2{,}000 \times 0.25 + 160 + 250 \times 0.35) = 44.8$.

3a. **Heat to Decompose Limestone.**—B.t.u. per pound of iron charged = $0.02 \times 0.95 \times 813 = 15.4$.

4a. **Heat to Evaporate Moisture in Coke.**—B.t.u. per pound of iron charged = $11 \times 0.02 \times 966 = 2.1$.

5a. **Heat Stored up in Lining.**—The weight of the lining below the charging door figures out approximately 27,400 pounds. Estimating its average temperature to be 1,000° F., the B.t.u. per pound of iron charged =

$$\frac{27{,}400 \times 1{,}000 \times (0.193 + 0.000043 \times 1{,}000) = 80.9.}{80{,}000}$$

6a. **Heat to Decompose Moisture of Blast.**—A dew-point of 50° F. corresponds to 0.0075 pound of water per pound of moist air. Hence the B.t.u. per pound of iron charged = $9 \times 0.9 \times 0.11 \times 0.0075 \times 5{,}800 + 38.8$.

7a. **Heat Sensible in Gases.**—The weight of the gases per pound of carbon burned works out as follows: $CO_2$, 2.200; CO, 0.933; N, 6.910; H, 0.007; total, 10.050 pounds. The average specific heat is $0.23 + 0.000023t$. Hence the B.t.u. per pound of iron charged = $0.11 \times 0.9 \times 10.05 \times 1{,}600 \times 2{,}668 = 424.7$.

8a. **Heat Potential in Gases.**—B.t.u. per pound of iron charged = $0.11 \times 0.9 \times 0.933 \times 4{,}370 = 403.7$.

9a. **Heat Lost by Radiation Plus Error and Unaccounted For.**—This amount is found by difference to be 174.2 B.t.u. per pound of iron charged. Summarizing these items, we get the following heat balance expressed in B.t.u. per pound of iron charged:

| Sources of Heat | | Heat Used and Lost | |
|---|---|---|---|
| 1. Combustion of fuel | 1470.4 | 1a. In molten iron | 432.0 |
| 2. Oxidation of iron | 74.0 | 2a. In molten slag | 44.8 |
| 3. Oxidation of silicon | 31.5 | 3a. To decompose limestone | 15.4 |
| 4. Oxidation of manganese | 7.4 | 4a. To evaporate moisture | 2.1 |
| 5. Sensible in coke | 1.1 | 5a. To heat up lining | 80.8 |
| 6. Sensible in iron | 7.2 | 6a. To decompose moisture | 38.8 |
| 7. Sensible in limestone | 0.3 | 7a. Sensible in gases | 424.7 |
| 8. Sensible in blast | 12.6 | 8a. Potential in gases | 403.7 |
| 9. Formation of slag | 12.0 | 9a. Radiation and error | 174.2 |
| | 1616.5 | | 1616.5 |

The great source of wasted heat in the cupola is in the gases escaping at the top. If these losses could be eliminated it should be possible to charge some 22 pounds of iron for each pound of coke, have the gases come off from the top perfectly cold and containing no CO, and the iron satisfactorily melted. Actually this cannot be done.

In the cupola there is a deep bed of carbon (coke) which is being replenished from above as fast as it is consumed. Under these conditions, with carbon always in excess, the products of combustion depend upon the temperature and time of contact of the gases with the excess carbon. The tendency is towards the formation of CO at high temperatures and $CO_2$ at lower temperatures. Now in the cupola there is a zone immediately in front of the tuyeres which is cooled by the inrushing blast of cold air and in which $CO_2$ is formed, this formation of $CO_2$ being also aided by the fact that in this space oxygen is supplied faster than the surface of the coke present can combine with it. Further in and up in the cupola the temperature is much higher and conditions are such as to favor the reduction of the $CO_2$ to CO, according to the reaction $CO_2 + C = 2\,CO$. Time, however, is necessary for this reaction to take place, and since the velocity of the gases is very great and they are in contact with the hot carbon for only an instant, more or less $CO_2$ invariably passes through unchanged. On the other hand, it is impossible to make the velocity of the gases so great as to prevent entirely the reduction of $CO_2$ without creating intensely oxidizing conditions inside of the cupola and, hence, destroying its usefulness as a melting furnace.

The temperature of the top gases depends on the amount of heat absorbed by the stock in proportion to the total amount generated in the zone of combustion. More heat is generated when carbon is burned to $CO_2$, and the rapid rate of blowing necessary to the formation of a large percentage of $CO_2$ increases the velocity of the gases and gives less opportunity for the absorption of heat by the stock.

## IRON CASTINGS

### NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Physical Properties.**—The physical characteristics of cast iron are to be in accordance with the following table:

| Grades of Iron Castings | Tensile strength (pounds per square inch) — Length of test piece not less than 2 inches | Transverse breaking load (for bar 1 inch square loaded at middle and resting on supports 1 foot apart) | Purposes for which intended |
|---|---|---|---|
| 1 | 20,000 (min.)..... | 2,200 (min.).......<br>2,800 (max.) | Steam cylinder and valve-chest casings.<br>Steam turbine casings, steam turbine parts.<br>Gas-engine cylinder and valve-chest casings.<br>Internal-combustion engine cylinders and valve-chest casings. |
| 2 | 20,000 (min.)..... | 2,500 (min.)....... | Cylinder liners and valve-chest liners. Steam, gas and internal-combustion engines.<br>Cylinder and valve-chest liners, small gas engines, and internal-combustion cylinders when cast in one piece. |
| 3 | 20,000 (min.)..... | 2,200 (min.)....... | Other important parts, such as main and auxiliary engine parts, etc. |
| 4 | To be inspected to see if they are in all respects suitable for the purposes for which they are intended. | | Minor parts, such as furnace fittings, etc. |

3. **Placing of Order.**—The grade and quality of the metal will be specified on the order.

4. **Hardness Requirement.**—Great care must be taken to determine that the machinery specifications for *hardness* of cylinders, liners, and valve-chest liners are complied with, and a test piece from the casting should be machined in order to show the degree of hardness.

5. **Quality of Material.**—The castings must be of uniform grain, smooth, free from blow-holes, porous places, shrinkage, and other cracks or defects, and must be well cleaned.

## TESTS

6. **Number of Tests.**—Sound test pieces shall be taken in sufficient number to exhibit the character of the metal in the entire piece from all castings requiring physical test.

7. **Additional Tests.**—The inspector may require from time to time such additional tests as he may deem necessary to determine the uniformity of the material.

8. **Rejection on Delivery.**—Iron castings may be rejected at the place of delivery for surface or other defects either existing on arrival or developed in working or storage, even though the material may have passed the required inspection at the place of manufacture.

## FINISH

9. **Surface Inspection.**—The scale shall be removed from the unfinished parts of the inside of all cylinders, cylinder covers, and valve-chest covers, and from the unfinished parts of all cylinder and valve-chest liners, and from ports and passages of cylinders and valve chests, either by pickling or other approved process as may be required.

10. **Finished Size.**—All engine castings must finish to blue-print size.

11. **Marking and Stamping.**—Each casting, if large enough, shall be stamped with heat number, figures to be not less than ½ inch long, and shall have size and order number plainly marked with white paint.

12. **Inspection Stamps.**—Castings which have passed inspection must show the U. S. anchor and other stamps necessary for identification, encircled by white-paint marks.

## MALLEABLE CAST IRON

The following is an abstract of a paper read by Dr. Richard Moldenke before the Am. Foundrymen's Ass'n., 1903.

While nominally the composition of a good malleable casting is but little different from that of a car wheel, the fact that it can be twisted, bent and hammered out hot or cold and has double the tensile strength shows that the constitution of the casting is quite different. This difference may be traced to the condition of the carbon. In the ordinary gray casting we may have some 3 to 3½ per cent graphite present. In malleable castings we have the same amount as graphite in the analysis, but radically different in characteristics. This form of carbon due to the annealing process has been called temper carbon by Professor Ledebur, who first described it in connection with the malleable (Ger. " temper ") process.

The tensile strength of malleable castings should run between 42,000 and 47,000 pounds per square inch; castings showing only 35,000 pounds are serviceable for ordinary work. It is not advisable to run beyond 54,000 pounds per square inch, for the resilience is reduced, and one of the most valuable properties of the malleable casting impaired.

The elongation of a piece of good "malleable" will lie between 2½ and 5½%, measured between points 2 inches apart. The thicker the piece the smaller the elongation. In making the transverse test, the deflection of an inch square piece, resting upon supports 12 inches apart, should be over ½ inch, the breaking weight being at least 3,500 pounds. Very soft iron often deflects 2½ inches under the test, but this is exceptional and may not be reproduced continuously.

The high resilience, or resistance to shock, in "malleable" is its most useful characteristic. Only where an exceedingly high tensile strength is required, as in the car couplers for the heavy modern trains, is the malleable casting being gradually replaced by steel castings.

**Composition and Structure.**—Originally cast to be perfectly chilled—that is, with the carbon all combined—and a contraction of some 1¼ inches to the foot, the annealing process serves to expel the carbon from its state of combination, depositing it between the crystals of the iron, not in the crystalline graphite of the gray iron, but as an amorphous form not unlike lampblack. At the same time an expansion equal to half of the original contraction takes place, the net result being a shrinkage allowance for the pattern identical with that for gray iron castings of similar shape and thickness. Besides this expulsion of the carbon from its combination, there is a removal of some of it from the outer portions of the casting. This amounts to nearly all in the skin to nothing ¼ inch inward.

It will be noted that owing to the removal of varying amounts of carbon from the skin to the interior no carbon determination of a malleable casting is of any value, unless the sample is taken before the anneal, and even then it is only good for the total carbon. For an annealed piece of sample taken from the center of the fracture with at least ⅜ inch untouched around the drill would give a fair indication of the carbon contents, but cannot claim accuracy.

Formerly charcoal iron about 4% carbon was the rule in malleable castings; in these days of coke irons and steel additions to reduce the carbon this may run as low as 2.75% before trouble ensues in the anneal, if not already in the foundry through excessive cracking and shrinkages. With the modern demand for a high tensile strength it is well to place the lowest limit at 2.75%, and the upper limit for common work would be found in the saturation point of this grade of iron, or 4.25%. It is absolutely necessary that the hard casting be free from graphite; even a small amount of this indicates an open structure with consequent ruin to the work in the anneal from penetrating oxygen. To keep the carbon in the combined state is the function of the silicon percentage arranged for in the mixture, the rate of cooling due to the cross section, the pouring temperature, sand, etc.

The sulphur content is quite important, the percentage should not be allowed to go over 0.05, and it is wise to hold the pig iron below 0.04, and to see that the fuel used is not too rich in sulphur.

Manganese is seldom troublesome, as it does not often exceed 0.40 in the mixture, which means 0.10 to 0.20 in the casting. Above 0.40 in the casting it begins to give trouble in the anneal, therefore, manganese should be kept low.

Phosphorus should not exceed 0.225, and is better kept below this.

**Silicon.**—In general the thicker the casting the lower the silicon allowable in order to get a white iron in the sand. Thus for the heaviest class of work the silicon of the casting should not exceed 0.45. For ordinary work 0.65 is the point to be sought for. Agricultural work may run up to 0.80, while the lightest casting may have 1.25% without danger, though it is not advisable to exceed this limit for anything.

American practice differs from the European in several respects; we have a comparatively short anneal—that is, we aim at a conversion of the carbon rather than its removal. Over there it is desired to get all carbon out, so that a wrought iron casting, if it may be so called, may result.

The common American practice is to use the reverberatory, or air-furnace, either with or without the top blast over the bridge to hasten the melting. While not many malleable establishments have the open-hearth furnace it is undoubtedly an economical melter, provided it be kept busy. It also means a man who will push the pigs into the bath as quickly as they can be cared for, mix his iron well and fire sharp and quick so that the process becomes one of melting only rather than a refining or burning out of large quantities of silicon and carbon.

Under fair conditions, with three heats daily from a 10-ton open-hearth furnace using producer gas as fuel, the ratio is about one of coal to six of iron. In the reverberatory furnace the fuel ration is one to four at best, and often only one to two. It is not advisable to make larger heats than 15 to 18 tons, as the time consumed in melting,

and especially in pouring from the small ladles after tapping, becomes so great that the bath is seriously damaged by undue oxidation and overheating.

For making malleable castings, the open-hearth furnace should be pushed very hard for a time, obtaining a short, sharp heat. The silicon of the heat may be calculated for a loss of 20 to 25 points, whereas from 35 upward is the rule in other processes.

The cupola still turns out a considerable tonnage of malleable castings, but this process will be gradually superseded by the furnace method, chiefly on account of the better grade of work turned out by the latter. Cupola iron requires some 200° F. more than furnace iron to anneal it properly. It seems strange that it should be so, possibly the structure of cupola iron is so close that it requires more effort to get the crystals apart and to effect the liberation of the carbon from its state of combination. Whether this is due to the contact of the metal with the fuel as it trickles down in thin streams and drops is hard to say, but the difference certainly exists and must be provided for in the anneal.

In the annealing process we find two extremes leading to about the same results: A short anneal at a very high heat is as effective as a comparatively long anneal at a much lower temperature. That is to say, we can change the carbon in a casting, by placing it overnight in a melting furnace which has cooled below the melting point of iron, or do the same thing in the annealing oven at a much lower temperature, but giving it a week's time. Of the two methods the latter is preferable, as it not only permits the change in the carbon but also gives the carbon time to get out. The result is a good, reliable casting, while in the hurry-up processes one never knows whether they are annealed at all.

The annealing process may be described by a curve which runs up quickly, remains horizontal for a short time and then drops very gradually. That is, a sharp heating up, in the shortest safe time possible, then a shutting off of the dampers and maintaining of the temperature evenly for a period of, say, two full days at least, and then a gradual cooling down to at least a black heat before dumping.

Furnace iron of average thickness must have received over 1,250° F. after coming up, until cutting off the heat, to be safely annealed. Perhaps even then some of the work must be put back for another anneal. A safer limit is 1,350° F., and no more is necessary. This temperature must exist in the coldest part of the furnace, or usually at the lower part of the middle in the front row pots. As a rule the upper space of an oven is some 200° F. higher than this.

Translating these temperatures, we find that 660° C. (1,220° F.) is the lowest point for successful annealing of furnace iron, while 780° C. (1,436° F.) is the safest one. For cupola iron the temperature should be about 850° C. (1,562° F.).

## SPECIFICATIONS FOR MALLEABLE IRON CASTINGS

Malleable iron castings may be made by the open-hearth, air furnace or cupola process. Cupola iron, however, is not recommended for heavy nor for important castings.

**Chemical Properties.**—Castings for which physical requirements are specified shall not contain over .06 sulphur nor over .225 phosphorus.

**Physical Properties.**—(1) Standard test bar shall be 1 inch square and 14 inches long, without chills and with ends perfectly free in the mold. Three shall be cast in one mold, heavy risers insuring sound bars. Where the full heat goes into castings which are subject to specification, one mold shall be poured two minutes after tapping into the first ladle, and another mold from the last iron of the heat. Molds shall be suitably stamped to insure identification of the bars, the bars being annealed with the castings.

(2) Of the three test bars from the two molds required for each heat, one shall be tested for tensile strength and elongation, the other for transverse strength and deflection. The other remaining bar is reserved for either the transverse or tensile test, in case of the failure of the two other bars to come up to requirements. The halves of the bars broken transversely may also be used for tensile strength.

(3) Failure to reach the required limit for the tensile strength with elongation, as

also the transverse strength with deflection, on the part of at least one test rejects the castings from that heat.

(4) Tensile Test.—The tensile strength of a standard test bar for castings under specification shall not be less than 42,000 pounds per square inch. The elongation measured in 2 inches shall not be less than $2\frac{1}{2}\%$.

(5) Transverse Test.—The transverse strength of a standard test bar, on supports 12 inches apart, pressure being applied at center, shall not be less than 3,000 pounds, deflection being at least $\frac{1}{2}$ of an inch.

**Test Lugs.**—Castings of special design or of special importance may be provided with suitable test lugs at the option of the inspector. At least one of these lugs shall be left on the casting for his inspection upon his request therefor.

**Annealing.**—(1) Malleable castings shall neither be over nor under annealed. They must have received their full heat in the oven at least sixty hours after reaching that temperature.

(2) The Saggers shall not be dumped until the contents shall at least be black hot.

**Finish.**—Castings shall be true to pattern, free from blemishes, scale or shrinkage cracks. A variation of $\frac{1}{16}$ of an inch per foot shall be permissible. Founders shall not be held responsible for defects due to irregular cross sections and unevenly distributed metal.

## MALLEABLE IRON CASTINGS

### NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form a part of the specifications.

2. **Open-Hearth or Air-Furnace.**—The malleable iron castings for which physical requirements are specified may be made either by the open-hearth or air-furnace process.

3. **Physical and Chemical Properties.**—The physical and chemical characteristics of malleable iron castings are to be in accordance with the following table:

| Material | Tensile Strength per Square Inch (Min.) | Elongation in 2 Inches (Min.) | Transverse Breaking Bar 1 Inch Square, 12 Inches long, loaded at Center | Deflection | Maximum | |
|---|---|---|---|---|---|---|
| | | | | | Sulphur | Phosphorus |
| | *Pounds* | *Per Ct.* | *Pounds* | *Inch* | *Per Ct.* | *Per Ct.* |
| Open-hearth or air-furnace process... | 36,000 | 3 | 3,000 | $\frac{1}{2}$ | 0.08 | 0.225 |

4. **Freedom from Defects.**—Castings must be true to pattern, free from scale, blemishes, shrinkage cracks, or other defects.

5. **To Have Sufficient Anneal.**—Castings must be neither "over" nor "under" annealed. They must have received their full heat in the oven at least 60 hours after reaching that temperature, and shall not be dumped until they are at least "black hot."

6. **Test Bars; How Cast and Number.**—Test bars to be cast accurately 1 inch square, not less than 14 inches long, and of sufficient number to insure sound ones for all test purposes.

7. **Appearance After Machining.**—The castings when machined should show the annealing process has changed the carbon from the combined carbon to graphite carbon.

8. **Pipe Flanges.**—For pipe flanges the castings should be made sufficiently malleable to permit of steel tubing being satisfactorily expanded into them without distorting the shape or cracking the castings. If more than one casting of any size ordered will not stand the expanding, they must be replaced with satisfactory castings.

9. **Specifications for Malleable-Iron Pipe Fittings.**—These specifications are independent of Specifications for Malleable-Iron Pipe Fittings, Black or Galvanized, issued by the Navy Department.

## SEMI-STEEL CASTINGS

Melting steel with iron in a cupola adds strength to the resultant casting; to what extent this is so, and the best proportion of steel to use are not clearly understood. To ascertain definitely in regard to these and to trace if possible the connection between percentage of total carbon in the iron and its tensile strength, Mr. H. E. Biller made the tests summarized in the accompanying table:

### Properties of Semi-steel Castings

| | Chemical Composition. | | | | Carbon | | | Breaking strength | | Steel used in mixture, per cent. |
|---|---|---|---|---|---|---|---|---|---|---|
| No. | Silicon. | Sulphur. | Phosphorus. | Manganese. | Combined. | Graphitic. | Total. | Tensile. | Transverse. | |
| 1 | 1.43 | 0.047 | 0.564 | 0.82 | 0.67 | 3.14 | 3.81 | 23,060 | 2,550 | 0 |
| 2 | 1.50 | .065 | .532 | .33 | .64 | 3.44 | 3.08 | 30,500 | 2,840 | 25 |
| 3 | 1.76 | .062 | .488 | .53 | .51 | 3.12 | 3.63 | 22,180 | 2,440 | 0 |
| 4 | 1.76 | .139 | .515 | .57 | .43 | 2.94 | 3.37 | 27,090 | 2,770 | 12½ |
| 5 | 1.77 | .069 | .339 | .49 | .56 | 2.87 | 3.43 | 32,500 | 3,120 | 12½ |
| 6 | 1.83 | .100 | .610 | .55 | .51 | 2.44 | 2.95 | 36,860 | 3,280 | 25 |
| 7 | 1.75 | .089 | .598 | .35 | .74 | 2.12 | 2.86 | 30,160 | 3,130 | 37½ |
| 8 | 1.96 | .104 | .446 | .44 | .63 | 3.18 | 3.81 | 21,950 | 2,230 | 0 |
| 9 | 2.12 | .037 | .410 | .26 | .38 | 3.26 | 3.64 | 21,890 | 2,470 | 12½ |
| 10 | 2.16 | .060 | .315 | .20 | 1.06 | 2.30 | 3.36 | 26,310 | 2,670 | 12½ |
| 11 | 1.97 | .093 | .470 | .48 | .57 | 2.83 | 3.40 | 32,530 | 3,050 | 37½ |
| 12 | 2.35 | .061 | .515 | .56 | .54 | 3.40 | 3.94 | 21,990 | 2,200 | 0 |
| 13 | 2.53 | .104 | .490 | .54 | .60 | 2.56 | 3.16 | 33,390 | 2,850 | 25 |
| 14 | 2.36 | .064 | .327 | .24 | 1.08 | 2.15 | 3.23 | 31,560 | 3,200 | 25 |

The tensile and transverse strengths given in the table are the average of two, and in some cases three test bars. For tensile strength a 1⅛-inch round bar was used. The transverse strength was obtained from a 1-inch square bar placed on supports 12 inches apart.

The object sought in classification into sets was to have the silicon about equal in the tests of each set; the other elements being as nearly alike in quantity as it was possible for him to get them.

Set 1.—Test Nos. 1 and 2 show comparatively little difference in chemical content, except in manganese and graphite. As the manganese in No. 1 should be beneficial to the strength of the bar, the only way to account for the greater strength of the iron from No. 2 is the lower percentage of graphite, or the molecular structure resulting from the 25% of steel in the mixture.

Set 2.—Comparing Nos. 3 to 7 the strength increases with percentage of steel used and decrease of total carbon, with the exception of No. 7; in this 37½% of steel was used, and the total carbon was less than in any other test, but it is weaker than either Nos. 5 or No. 6. This being a solitary case it can hardly be used as proof that 37½% of steel is more than it is well to melt in a cupola. But test No. 11, which also contained 37½% of steel and more carbon, was only a little stronger.

Test No. 4 was considerably weaker than No. 5, but its higher percentage of sulphur with its lower combined carbon would seem to indicate that these bars were either cooled slower, or poured from duller iron than were the bars from No. 5, which may account for their being weaker than the No. 5 bars.

Set 3.—Nos. 8 to 11 we note that No. 9, although containing 12½% of steel is no stronger than No. 8, in which there was no steel. And No. 10 with 1.06 combined carbon, and 12½% of steel, gives less strength than might be expected. As these tests are so much lower in manganese than Nos. 8 and 11, it may be that their weakness is due either to the lower manganese or to the conditions of melting, which reduced the percentage of manganese so much more than in Nos. 8 and 11. The four charges each contained about 50% manganese before melting.

Set 4.—Nos. 13 and 14, each from charges containing 25% of steel, show a marked increase in strength over No. 12.

All the tests from charges containing 25% of steel are stronger than those from charges containing but 12½%, with the exception of No. 5, which is stronger than two of the tests which had 25% of steel in the mixture.

These tests were made with pig iron, ferro-silicon, and steel scrap, no cast-iron scrap being used. This, in order to better control the percentage of the elements in the iron. In some cases when a large percentage of steel was added, it was necessary to use ferro-silicon to get the desired amount of silicon in the charge. Two tests were taken from No. 13, which contained 1,000 pounds of steel, 400 pounds of ferro-silicon (8.5% silicon), and 2,600 pounds of pig iron. The charge was tapped from the cupola into a ladle, and the tests taken at different times, as the iron was being poured from the ladle. The one sample contained 2.53 and the other 2.54% of silicon. Two tests, taken in the same way from No. 14, contained 1.97 and 1.94% of silicon. This charge was made up of 1,500 pounds steel, 450 pounds ferro-silicon, and 2,050 pounds of pig-iron. Similar tests from charge No. 2, which was made up of 1,000 pounds steel and 3,000 pounds pig iron, contained 1.50 and 1.52% silicon. These three cases offer pretty strong proof that the pig iron, steel, and ferro-silicon mixed thoroughly.

Although of a limited number, the tests given seem to indicate that 25% of steel will add about 50% to the strength of the iron; and 12½% of steel, approximately 25%. The tests containing 37½% of steel were hardly as much improved in strength as those with 25% of steel, from which we may infer that the limit of the amount of steel it is beneficial to melt with iron in a cupola, is between 25 and 37½%.

## STEEL CASTINGS

Steel castings combine in large measure the convenience of gray iron castings with a strength approximating that of forgings. In structural material construction, such as bridges, blast furnaces, mills, large buildings, etc., the engineer is specifying steel rather than iron castings. Maritime construction turns out a vessel composed entirely of steel plates and castings.

Castings are commonly of open hearth steel which may be produced by the acid or by the basic process. A résumé and condensation of the two processes would be as follows: The furnace is, in each instance, practically the same, the difference being in the lining of hearth of furnace. The acid process eliminates manganese, silicon and carbon only, the phosphorus and sulphur being practically unchanged from the initial charge. The basic process eliminates all the ingredients above specified, except silicon, which is very deleterious to this process. But silicon is a subject for the blast furnace treatment, and can there be kept low. Steel is now being produced of such chemical and physical structure that no chemical or physical determination will demonstrate by which process it was made, whether it is a product of an acid or basic open-hearth furnace. This, then, completely obviates the pertinency of the question by which process was the steel produced.

In a regenerative or open-hearth furnace, the charge is exposed to the direct action of the reducing flame, and, when melted, the carbon is also eliminated; to the resultant bath manganese is added, and the molten iron is recarbonized, thus producing steel. To obtain the requisite heat, regeneration is practiced; the general practice is with producer gas and air. The regenerators play a specific part, and that is to preheat the ingoing gases and air; to accomplish this end the chambers or regenerators should contain 60 to 100 cubic feet per ton of steel.—*L. L. Knox.*

## SPECIFICATIONS FOR STEEL CASTINGS

Ordinary castings, those in which no physical requirements are specified, shall not contain over 0.40% of carbon, nor over 0.08% of phosphorus.

Castings which are subjected to physical test shall not contain over 0.05% of phosphorus, nor over 0.05% sulphur.

Tested castings shall be of three classes: Hard, Medium, and Soft. The minimum physical qualities required in each class shall be as follows:

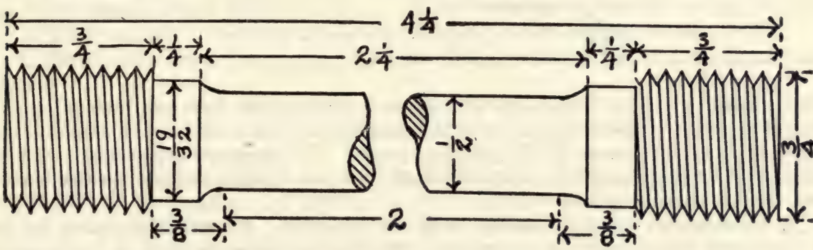
| | Hard Castings | Medium Castings | Soft Castings |
|---|---|---|---|
| Tensile strength, lbs. per sq. in. | 85,000 | 70,000 | 60,000 |
| Yield point, lbs. per sq. in. | 38,250 | 31,500 | 27,000 |
| Elongation, per cent in two ins. | 15 | 18 | 22 |
| Contraction of area, per cent. | 20 | 25 | 30 |

A test to destruction may be substituted for the tensile test, in the case of small or unimportant castings, by selecting three castings from a lot. This test shall show the material to be ductile and free from injurious defects and suitable for the purpose intended. A lot shall consist of all castings from the same melt or blow, annealed in the same furnace charge.

Large castings are to be suspended and hammered all over. No cracks, flaws, defects, nor weakness shall appear after such treatment.

A specimen one inch by one-half inch shall bend cold around diameter of one inch without fracture on outside of bent portion through an angle of 120° for soft castings and 90° for medium castings.

The standard turned test specimen one-half inch diameter and two inch gauged length, shall be used to determine the physical properties specified. It is shown in the following sketch:




The number of standard test specimens shall depend upon the character and importance of the castings. A test piece shall be cut cold from a coupon to be molded and cast on some portion of one or more castings from each melt or blow or from the sink-heads, in case heads of sufficient size are used. The coupon or sink-head must receive the same treatment as the casting or castings, before the specimen is cut out, and before the coupon or sink-head is removed from the casting.

One specimen for bending test one inch by one-half inch shall be cut from the coupon or sink-head of the casting or castings. The bending test may be made by pressure, or by blows.

The yield point specified shall be determined by the careful observation of the drop of the beam or halt in the gauge of the testing machine.

Turnings from the tensile specimen, drillings from the bending specimen, or drillings from the small test ingot, if preferred by the inspector, shall be used to determine whether or not the steel is within the specified limits in phosphorus and sulphur.

Castings shall be true to pattern, free from blemishes, flaws or shrinkage cracks. Bearing surface shall be solid, and no porosity shall be allowed in positions where the resistance and value of the casting for the purpose intended will be seriously affected thereby.

## STEEL CASTINGS

### NAVY DEPARTMENT

**1. General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Process of Manufacture.**—Castings shall be made by a process approved by the bureau concerned.

3. **Chemical and Physical Properties.**—The physical and chemical requirements of steel castings shall be in accordance with the following table:

| Class Symbol | Chemical Composition: Not Over— | | Physical Requirements | | | | |
|---|---|---|---|---|---|---|---|
| | P. | S. | Minimum Tensile Strength | Minimum Yield Point | Minimum Elongation | Minimum Reduction of Area | Bending Test; Cold Bend (Not Less Than) |
| | | | *Pounds per Sq. In.* | *Pounds per Sq. In.* | *Per Ct. in 2 Ins.* | *Per Ct.* | |
| Special... | 0.04 | 0.04 | 90,000 | 57,000 | 20 | 30 | 90° about an inner diameter of 1 inch. |
| A....... | .05 | .05 | 80,000 | 35,000 | 17 | 20 | 90° about an inner diameter of 1 inch. |
| B....... | .06 | .05 | *Maximum* 80,000 *Minimum* 60,000 | 30,000 | 22 | 25 | 120° about an inner diameter of 1 inch. |
| C....... | .06 | .05 | ..... | ..... | .. | .. | |

4. **Class C.**—Class C castings will not be tested unless there are reasons to doubt that they are of a quality suitable for the purpose for which they are intended. Tests, if required, may be made at the building yards. The inspector will select a sufficient number of castings and have them crushed, bent, or broken, and note their behavior and the appearance of the fracture.

5. **Treatment.**—(a) All castings shall be annealed. All annealing shall be done in a properly constructed pit or furnace. The furnace must be held at the annealing temperature long enough to insure that all of the interior of the casting or castings being annealed have been brought to that temperature. After the castings have been soaked at the proper annealing temperature they must be allowed to cool slowly in the furnace, carefully protected from drafts of air. Unless otherwise directed by the inspector, castings must not be removed from the furnace until they have been cooled down to the temperature at which the color dies (about 700° F.). The number of hours requisite for raising the castings to the proper temperature, the length of time during which they should be soaked at that temperature, and the period required for slow cooling in the furnace or in the air, may be prescribed by the bureau concerned, if it is so desired.

(b) Additional or Subsequent Treatment.—Castings shall not be subjected to additional annealing or subsequent treatment without the knowledge and consent of the inspector, and when this is done the inspector will make such additional tests as will satisfy him that the retreated castings meet the requirements.

(c) Castings that have received any treatment without the consent of the inspector shall be rejected.

(d) Cleaning.—All castings shall be thoroughly cleaned before inspection, after final treatment.

6. **Test Specimens, Number, and Location.**—(a) Coupons from which test specimens are to be taken shall, whenever practicable, be cast on the body of the casting. The number and location of the coupons shall be such as to thoroughly exhibit the character of the metal throughout the casting. When the use of these cast-on coupons is not practicable, the test bar shall be taken from a coupon cast with and gated to the casting, or with small runners to the gate. If necessary, coupons may be cast separ-

ately, but in all such cases the approval of the inspector must first be obtained. Coupons shall not be detached from the casting until it has received its final treatment.

(b) Particular care will be exercised with castings estimated to weigh 200 pounds or over that the test specimens taken from the castings shall be in sufficient number and so located as to thoroughly exhibit the character of the metal of the entire casting.

(c) Tests, Individual and Lot.—Castings, the estimated weight of which is 200 pounds or over, will be tested by individual tests. Other castings shall be tested by lots as follows: A lot shall consist of castings from the same heat and annealed in the same furnace charge. From each lot two tensile and one bending specimen shall be taken, and the lot shall be passed or rejected on the results shown by these specimens. Manufacturers, for their own safety, will provide enough coupons for extra tests in case of flaws showing in the test specimens.

(d) In the case of castings tested by lots, the test pieces may be taken from the body of a casting from the lot if so desired by the manufacturer. When a number of small castings have been cast on the same heat with two or more larger castings carrying test coupons, the small castings may, at the discretion of the inspector, be represented by the test bars from the large castings. A casting from which an unsound test specimen has been taken shall receive particular care to detect porosity or other unsoundness in the casting itself.

(e) A "lot" or "heat test," provided for in the preceding paragraphs, will not be permitted unless the manufacturer complies with the instructions hereafter relative to identification.

7. **Rejection After Delivery.**—The acceptance of any casting by the inspector will not relieve the makers thereof from the necessity of replacing the casting should it fail in proof test or trial or in working or exhibit any defect after delivery.

8. **Percussive Test.**—(a) Large castings shall be subjected to hammer tests as follows:

(b) The castings are to be suspended and hammered all over with a hammer weighing not less than 7½ pounds. If cracks, flaws, defects, or weakness appear after such treatment, castings will be rejected.

9. **Surface Inspection.**—(a) All castings shall be thoroughly cleaned and, where practicable, have the gates and heads removed before being submitted to the inspector for inspection in the green. The removal of heads and gates by burning will not be permitted. All castings shall be submitted in the green—that is, before they have received any treatment other than cleaning.

(b) Castings shall be sound and free from all injurious defects. Particular search will be made at the points where the heads or risers join the castings, as unsoundness at this point may extend into the castings.

(c) The closing of cracks and cavities by hammering and plugging will not be tolerated.

(d) Welding When Permitted.—Minor defects that do not impair the structural value of the casting may be welded up by an approved process if, in the judgment of the inspector, they are unimportant, but no such burning in or welding the defects will be permitted except after an inspection by the inspector of the casting in the green, with the defect thoroughly cleaned out to show its extent. Such welding should always be performed before annealing, and in no case shall welding be done without being subsequently annealed. The castings shall be inspected by the inspector after the defect has been welded up and before being annealed. Surface defects and cavities which are of more than minor importance shall not be so welded up except by permission of the inspector in charge of the district or of the bureau concerned. In no case will any welding be allowed on steam piping or any other casting used in connection with steam piping or subjected to steam pressure, nor in the following ordnance castings: Gun yokes and slides in region of the trunnions, elevating gear lugs, and recoil cylinder and spring cylinder bearings for same. White-lead marks shall be placed about defects which have been welded up, before shipment, in order that during any machining or other treatment at the manufacturing plant where used, special attention may be given this point.

10. **Chemical Analysis.**—Manufacturers shall furnish a chemical analysis of each

heat made in an approved manner, the process of analysis to be open to the inspector. The Government check analysis must show the heat to be in accordance with the specifications.

11. **Casting Record.**—(a) For the purpose of identifying castings inspected under these specifications the manufacturer shall, *upon request, furnish* the inspector with true copies of his shop order sheet, molding and pouring record, and a detailed list of the castings to be inspected, cast in each heat, showing manufacturer's analysis of the heat, name, pattern number, heat number, serial number, and estimated weight of each casting.

(b) Annealing Record.—For castings annealed a "Report of annealing" shall be furnished the inspector, showing the heat and serial number of each casting to be inspected in the annealing furnace charge, together with the time of raising to the soaking temperature, the time of soaking, the time of cooling, and the temperature at which soaking was done.

The record cards shall be exhibited to the inspector upon request.

(Note.—Steel castings for hawse pipe, turret tracks, and all important parts subject to crushing stresses or surface wear only shall be Class A castings, and those for stern post, rudder frames, and all parts subject to tension or vibratory strains shall be Class B castings, unless the bureau concerned otherwise directs.)

### SPECIAL PROVISIONS FOR ORDNANCE CASTINGS

12. **Patterns.**—Patterns for all large ordnance castings contracted for will be furnished by the Government, but the responsibility shall rest upon the contractors to supply castings that will finish to the drawing dimensions within the tolerances specified. The contractor shall report to the Government any alterations in the patterns that he may deem necessary to insure castings coming to the finished drawing dimensions, and shall, if required by the Government, make such alterations of the patterns. The actual cost of such alterations shall be borne by the Government.

## PLUMBAGO FOR FOUNDRY USE

### NAVY DEPARTMENT

Plumbago for foundry use shall be finely powdered, dry, free from coal dust or grit, and conform to the following requirements as to chemical composition:

**Volatile Matter.**—Not over 5 per cent.

**Ash.**—Not over 40 per cent.

**Graphite Carbon.**—Not less than 55 per cent.

**For Foreign Shipment.**—It must be delivered in good, well coopered, oak barrels, such as are used in the transportation of oil. Each barrel to be completely filled and to contain about 400 pounds of material. Barrels must have the bodies lined with elastic crinkled paper tubes and have sheets of ordinary strong paper properly fitted in tops and bottoms. The name of material, quantity, and name of manufacturer must be neatly stenciled on the heads.

At least 10 per cent of the barrels must be opened at random for inspection of contents.

**For Domestic Shipment.**—It must be delivered in No. 1 flour barrels, completely filled and containing about 250 pounds each. Top and bottom heads to be reinforced. The bodies of the barrels must be lined with elastic crinkled paper tubes and have sheets of strong ordinary paper properly fitted in bottoms and heads. The name of material, quantity, and name of manufacturer must be neatly stenciled on the heads.

At least 10 per cent of the barrels must be opened at random for inspection of contents.

## SECTION 8

# IRON AND STEEL FORGINGS. CARBON AND HIGH-SPEED STEELS. HEAT TREATMENT, FORGE EQUIPMENT

**Wrought Iron.**—From time immemorial wrought iron has been the principal, almost the only, metal employed by the smith at the forge. Its extended use in the arts has been due to its inherent properties being at once a malleable, ductile, weldable material of high tensile strength, high elastic limit, and of great reliability under permanent and alternating stresses. In recent years it has been, in great measure, superseded by mild steel, but only in articles which do not require welding.

Wrought iron is made from white cast iron by a process of elimination known as puddling, the purpose of which is to eliminate the graphite entirely and the combined carbon so far as to leave less than 0.20%, a quantity which does not wholly prevent welding but is sufficient to increase the strength, rigidity, and hardness of the iron.

Puddling by hand is commonly done in a reverberatory furnace. The pigs of white iron are broken up and placed in the hearth of the furnace, being intimately mixed with scales of oxide of iron obtained from the rolling mill. This mixture of iron and scale is subjected to an oxidizing flame, the temperature of the furnace being so regulated as to reduce the iron to a pasty condition; while in this condition the iron and the molten scales or cinder are constantly stirred by hand tools until the whole is thoroughly mixed, it is then formed into a ball as large as can be conveniently gotten through the furnace door. This newly converted mass of viscous iron and cinder or slag is then worked under a hammer, or placed in some form of squeezer, the slag with its contained impurities being driven out by pressure; the resulting bloom is then rolled into a muck bar, which is cut into short pieces, piled into a bundle, reheated to the welding point, and again hammered and rolled to further cleanse the iron of its impurities, the product being known as single refined iron; if subjected to a second piling, heating, hammering, or rolling it is known as double refined iron. This process of piling, reheating, and rolling may be repeated until the desired quality of iron is attained.

**Chemistry.**—As a chemical process it consists essentially in the elimination of carbon from pig iron in the action of the furnace flame upon the molten oxide of iron, the oxygen of which unites with the carbon in the pig iron, carbon dioxide is formed which passes off as a gas. The quantity of carbon remaining in the puddled iron is very small, usually between 0.05 and 0.10%, an amount insufficient to harden the iron by rapid cooling from a red heat.

The silicon in the pig iron unites with any free oxygen in the furnace, a basic silicate of iron is formed which passes off with the slag.

Manganese is readily removed from iron by oxidation; while restraining the oxidation of iron it permits oxidation of other elements combined with the iron, thus: Manganese present in pig iron, in which sulphur is also present as iron sulphide, changes the latter into manganese sulphide, liberating the iron. Manganese sulphide not being as soluble in iron as iron sulphide readily passes into the slag.

Phosphorus exists in pig iron as phosphide of iron. During the process of refining or puddling it is reduced to phosphate of iron which may be removed from iron by strong bases, such as oxide of iron, oxide of manganese, alkaline earths, such as lime, and by basic silicates in a strongly oxidizing atmosphere, passing off with the other impurities in the slag. When oxide of iron is reduced in the presence of an earthy phosphate, phosphorus is separated, and unites with the iron; 0.3% phosphorus in wrought iron makes it hard and diminishes its tenacity; 0.5% makes the iron cold-short but not red-short; 1.0% makes iron brittle. Phosphorus imparts to iron a coarse, crystalline structure, diminishes its strength, increases its fusibility, and makes it cold-short.

In the accompanying table a chemical analysis of an average sample of white iron, such as used in the puddling furnace, is given, together with analysis of plate iron of 55,000 pounds tensile strength. The plate analysis shows 0.80% cinder, of which only 0.04% is carbon.

| | Pig Iron Per Cent. | Wrought Iron Per Cent. |
|---|---|---|
| Iron | 89.44 | 99.20 |
| Carbon-graphite | .87 | .... |
| Combined | 2.45 | .04 |
| Manganese | 2.71 | .17 |
| Silicon | 1.11 | .15 |
| Sulphur | 2.51 | .03 |
| Phosphorus | .91 | .21 |
| Oxygen | .... | .20 |
| | 100.00 | 100.00 |

Wrought iron as distinguished from mild steel is traceable to its method of manufacture. Steel is of molten origin, wrought iron is of plastic origin, that is, it is made by stirring into an intimate mixture white pig iron heated to a pasty but not a molten condition in a bath of molten cinder, mechanically working it with a rake and after removal from the furnace squeezing out of the puddled mass much of its contained cinder, and not separating the molten metal by fusion as in the case of steel. Nearly all the carbon and most of the other impurities in the pig iron are taken up by the cinder leaving comparatively pure iron.

**Texture of Wrought Iron.**—Irons are said to be either fibrous or granular in texture. When worked directly from a bloom the forging presents a granular appearance; in large forgings, this grain is coarser at the center and finest near the surface. Should the process of hammering be continued, the forging will become, when considerably reduced in area, uniformly fine grained. If, however, instead of this continued hammering, the original forged billet be elongated by running it through a train of rolls the texture of a section cut longitudinally from the bar will have changed from granular to fibrous; but if the section be cut transversely or at right angles to this direction, the section will have a wholly different appearance. This is due, as explained by Sauveur:

In longitudinal section the ground mass of the metal consists of ferrite, similar in every respect to the crystalline grains of pure iron. The ferrite of wrought iron is not pure iron but rather a solution of iron in which are dissolved small quantities of silicon, phosphorus, and other minor impurities. Slag which has assumed the shape of fibers, or streaks, running in the direction of the rolling, imparts a fibrous appearance to the metal.

In transverse section there is a polygonal network indicating that the metal is made up of crystalline grains of ferrite. The slag, which in the longitudinal section occurred as fibers running in a direction parallel to the rolling, here assume the shape of irregular dark areas, corresponding to the cross-sections of the slag fibers. In both the longitudinal and transverse sections the ferrite grains are equi-axed, and show no sign of having been elongated in the direction of rolling.

Certain peculiarities noted by A. L. Hass in connection with Yorkshire iron show that, if the iron is nicked ⅛ inch deep around, say, a 1-inch bar, with a sharp set, and broken short over the anvil with a single blow, it shows a fracture in which the bar breaks dead short and square; the fracture is coarsely granular, resembling badly burned steel, only the granular structure is coarser. The bar nicked on one side only, and carefully bent with the nick a couple of inches from the edge of the vise or anvil, shows a beautiful gray, silky, fibrous structure, free from crystals and perfect in every way. This peculiarity, so perplexing to many iron-workers, is fully covered in the preceding explanation of the fibrous texture of wrought iron by Professor Sauveur.

Iron when pure presents but a single texture, and that the granular one. Puddling, as already explained, consists in stirring a mass of viscous iron in a bath of cinder; the latter prevents intimate contact of the particles of iron, it opposes thorough welding, and favors the production of fibrous texture, since during subsequent working the grains of iron accompanied by cinder can slide over each other in layers, and this gives to iron its fibrous texture.

**Malleability.**—So far as engineering work is concerned there are no restricting limitations to forgings of wrought iron, either as to size or shape, but soft fibrous irons are more malleable, that is, more easily worked than are hard granular irons.

**Tensile Strength.**—Wrought iron bars or plates, as delivered from the mill, should have a tensile strength not less than 48,000 pounds per square inch, and this should be accompanied by not less than 15% elongation in an 8-inch specimen. The fracture should be 90% fibrous. Plates and bars should bend cold without fracture through 135° over two thicknesses of plate and two diameters for bars, in order to meet the U. S. N. specifications.

Bar irons of good quality should have a tensile strength of about 53,000 pounds per square inch with an extension of about 20% in 8 inches; such irons must have good welding qualities; therefore the carbon and the phosphorus should each be less than 0.20%.

Irons which do not require to be welded may have a tensile strength of 60,000 pounds per square inch, with elongation of 18% in 8 inches. Such irons are apt to be hard, steely, and difficult to weld; they should, therefore, be restricted to uses direct from the bar or simple forging.

When tested across the fiber wrought iron plates and wide bars show a diminution in tensile strength of about 10% as compared with tests made in the direction of the fiber.

**Ductility.**—This property enables a material to be drawn out without breaking. It is also called elongation or extension in reports on the mechanical tests to which plates or bars are subjected. Elongation occurs when a ductile material is subjected to a tensile stress higher than its elastic limit, after which a permanent change of form takes place. It may be measured in a tensile testing-machine in two ways—by the actual amount of elongation in inches and parts of an inch, and by reducing the amount so found to percentage extension of its original length.

Wrought iron plates under 45,000 pounds tensile strength should show a reduction of area of not less than 12%; 45,000 to 50,000 pounds, 15%; 50,000 to 55,000, 25%; 55,000 pounds and over should show 35% reduction of area.

The following data were obtained from Government tests of wrought-iron plates, which it will be observed are of very high quality. These were short specimens:

| Thickness | Tensile Strength Pounds | Reduction of Area Per Cent. |
|---|---|---|
| $\frac{1}{4}$ inch with the grain | 58,373 | 38 |
| $\frac{1}{4}$ inch across the grain | 53,333 | 9 |
| $\frac{5}{16}$ inch with the grain | 62,195 | 43 |
| $\frac{5}{16}$ inch across the grain | 60,202 | 10 |
| $\frac{3}{8}$ inch with the grain | 56,270 | 25 |
| $\frac{3}{8}$ inch across the grain | 56,461 | 17 |

The behavior of wrought iron under tension will greatly depend upon its inherent hardness or softness; a hard specimen will elongate but little, while a softer specimen will be drawn out considerably, the middle part becoming gradually smaller, and fracture will ultimately take place at the smallest section, and probably at a lower strain than with a specimen of harder iron.

The stretching of wrought iron is seldom taken into account in engineering work, and the reason for selecting the softer iron is that it can be used with greater safety,

since when subjected to jar or sudden strain it is more likely to be drawn out than broken asunder, and thus gives timely warning before fracture.

**Elastic Limit.**—Wrought iron bars rolled, 4 inches diameter, having a tensile strength of about 46,000 pounds per square inch, will have an elastic limit averaging 50%. Bars of 2 inches diameter, tensile strength about 48,000 pounds per square inch, will have an elastic limit about 65%. Bars of 1-inch diameter having a tensile strength of about 51,000 pounds will have an elastic limit of about 70%. The above are adaptations from Beardslee's tests which were intended primarily to show the effect of continued working of wrought iron from a comparatively large area through successive operations to small bars.

For wrought iron, the following physical properties are taken as representing acceptable material in engineering work:

Bar iron in tension: 50,000 pounds tensile strength, elastic limit 26,000 pounds = 52%, with 18% elongation in 8 inches.

Shape iron in tension: 48,000 pounds tensile strength, elastic limit 26,000 pounds = 54%, with 15% elongation in 8 inches.

**Safe Load.**—Wrought-iron bars subject to varying stresses, such as screw bolts in engineering structures, should have a factor of safety of not less than 8, on the net area.

For chains the proof load up to 2.5 inches diameter is:

$$\textbf{Proof load in tons} = 18 \times (\textbf{diameter in inches})^2$$

The breaking strengths are placed at 40% above the proof loads. Thus the proof load on a 2-inch chain would be $18 \times 2^2 = 72$ tons (161,280 pounds). The area of a 2-inch bar is 3.14 square inches, then $161{,}280 \div 3.14 = 51{,}363$ pounds per square inch. The safe working load is one-half the proof load, or 25,681 pounds per square inch of sectional area of bar; accepting this, we have:

$$\text{Working load in tons of 2240 pounds} = \begin{cases} 9 \times D^2 \text{ for stud-link} \\ 6 \times D^2 \text{ for close link} \\ 4 \times D^2 \text{ for ordinary chains} \end{cases}$$

In which D = diameter of bar in inches.

**Compression.**—Of 10 specimens of wrought iron, cut from forgings of high quality, the softest began to yield with 22,800 pounds, and the hardest with 31,000 pounds, the average being 26,900 pounds. In each case weight was added until the specimen became shorter, by the $\frac{3}{1000}$ of an inch.

From experiments made with 10 other specimens taken from rolled bar iron of high quality, the specimens having been reduced in a lathe from 3-inch bars, the softest specimen required 31,000 pounds, and the hardest 35,000 pounds, or an average of 33,000 pounds.

Structures rarely ever fail from the actual crushing of the material; failure is more often due to the alteration of form which takes place, disturbing its fitness for the particular purpose for which it is intended. When a pillar, strut, or frame is long, it generally yields by flexure rather than actual crushing.

By increasing the stress upon short cylinders 0.533 inch diameter, length 1-inch, of wrought iron or soft steel, they are found to shorten gradually by bulging outwards in the middle. The effect of this change of form is to slightly stiffen the metal, and this affects the malleable or flowing property; unless the specimen is extremely soft, it will soon show symptoms of slight fissures or cracks at the part which is bulging. To prevent this, the annealing process must be resorted to, and with care the pillar can be flattened down to a thin disk, gradually presenting a larger surface for the machine to act upon. Reckoning the intensity of the ultimate pressure from the original dimensions, a stress of upwards of 100 tons per square inch is necessary to actually flatten down wrought iron.

When wrought iron or steel is flattened by compression, it might be supposed that the specific gravity would be increased; but such does not appear to be the case to any appreciable extent.

**Welding.**—Wrought iron possesses the property of welding when the two parts to be joined are brought up to a white heat. Welded joints are, when well made, scarcely

inferior to the original bar; but stays, braces, etc., for boilers should be made from whole stock if possible, because there is always more or less uncertainty about welded joints, particularly when the parts to be joined are of considerable diameter or thickness.

The lower grades of wrought iron make an apparent weld at almost a melting temperature, as well as at low heat. With the better grades of iron, that is, iron of high tensile strength, this cannot be done, and a heat between closer limits of temperature is necessary.

Welded chain is one of the principal uses for which wrought iron is still exclusively employed. In the making of a high-grade chain, reduction of area of the bar iron under tensile test is of value as affecting the finished chain. The elongation of sample links under tensile test bears a direct relation to the reduction of area obtained from the bar iron from which it is made. The greater the reduction of area in the bar, the greater will be the percentage of elongation in the finished chain. A well-made chain under tensile test never breaks in the weld, but always at the end of the link which is not welded, or at the side. A break at the weld proves poor workmanship, no matter what iron is used.

**Stiffening.**—This property of wrought iron is particularly valuable in the case of chains and similar link work. A chain, if of the best quality of iron and workmanship, will stiffen under breaking stress. Chains from a common grade of iron do not stiffen. The stiffening of chain links is a certain indication that the chain has been overstrained, and should be carefully annealed before further use.

**Annealing.**—When a piece of wrought iron has been subjected to a long series of blows, or violent jars, a change takes place in the structure of the iron. The change to rigidity which overtakes iron when worked cold may, according to Anderson, partly account for some of the frequent fractures of the chains of cranes, and this view is in some measure supported by the fact that when such chains are annealed at stated intervals, say annually, the liability to accident is greatly diminished.

A practical example of the value of annealing can be easily obtained from a wrought-iron chain. A link of a chain known to be in need of annealing can easily be broken by a single blow of a hammer, with the link held vertically on an anvil. The fracture is coarsely crystalline and the break is sharp and nearly square. After proper heat-treatment the next link can be flattened or maltreated in almost any manner short of actually cutting it, but it will not break.

**Temperature.**—Experimental research by Professor Rudeloff on the influence of low temperatures on iron and steel showed that much depends on the chemical composition of the material, but generally the ultimate strength is raised rapidly at first and slowly afterward, the yield point slowly at first and rapidly afterward, while percentage of elongation is generally decreased. The material is therefore less capable of resisting shock at low temperatures. At high temperatures metals decrease both in strength and ductility.

The effect of intense cold upon wrought iron as tested experimentally showed that of three pieces of a $\frac{3}{4}$-inch bar, one at 64° F. and the other, after having been exposed overnight to intense frost, were broken at 23° F. At 64° F. the tensile strength was 55,708 pounds, with elongation 24.9%.

At 23° F. the tensile strength was 54,387 pounds, with 23.0% elongation, showing that at the lower temperature the strength was 1321.6 pounds less.

The general effect of extreme cold upon wrought iron seems to affect its ductility in greater degree than its tensile strength.

# WROUGHT IRON FOR BLACKSMITHS' USE

## NAVY DEPARTMENT

**Process of Manufacture.**—The material shall be of the best quality of American refined iron puddled from all-ore pig metal, and free from any admixture of steel or scrap. Short pieces must not be used in piling.

**Physical and Chemical Requirement.**—All material shall be free from injurious defects and have a workmanlike finish.

For sectional areas above 4 square inches a reduction of 1% in elongation and contraction and a reduction of 500 pounds in tensile strength will be allowed for each additional 2 square inches, and a proportionate amount of reduction for fractional parts thereof, provided the ultimate strength shall not fall more than 3,000 pounds nor the elongation more than 3% below the requirements of the grade of iron tested.

**Tests.**—Material will be tested in sizes rolled, when practicable, and a sufficient number of tests shall be taken to exhibit thoroughly the character of the material. When material can not be tested in sizes rolled, test pieces will be prepared to a sectional area as large as possible within the capacity of the testing machine for tensile tests, and reduced to suitable size for bending or other physical tests. The number of bending and other physical tests shall equal the number taken for tensile tests.

**Nick Test.**—A bar nicked approximately 20% of its thickness and bent back at this point through an angle of 180 degrees must show a long, clean, silky fiber, free from slag or dirt, or any coarse crystalline spots. A few crystalline spots may be tolerated, provided they do not in the aggregate exceed 10% of the sectional area of the bar.

**Drift Test.**—A rod or bar will be punched and expanded by pointed drifts until a round hole is formed the diameter of which is not less than nine-tenths the diameter of the rod or width of the bar. Any indication of fracture, cracks, or flaws developed by this test will be sufficient cause for rejection of the lot represented by the rod or bar.

**Completed Forgings.**—Forgings, when of wrought iron, will be built up either from the rolled bars themselves or from fagots or slabs previously prepared by shingling from such rolled bars. No rolled bars of greater cross-section than 1-inch by 4 inches will be used either directly in the built-up forging or in the preparation of the fagots or slabs. Bending and tensile tests are to be made from the original bar before reworking into the forging, fagots, or slabs, where practicable, in accordance with requirements stated above. Additional tests will be taken from prolongations of the finished forging, using full-length specimens where practicable. The number of test pieces will be such as the inspector may consider necessary to insure that the material used is uniform in character.

The physical and chemical requirements shall be as follows:

**Special Grade.**—Minimum tensile strength, 48,000 pounds per square inch with minimum yield point of one-half ultimate strength. Minimum elongation, 26%. Minimum contraction area 40%. Maximum amount of phosphorus, 0.10%. Sulphur, 0.015%. Bending test: Cold, 180° around a diameter of one thickness. Quenching test: Heat to 1700° F. and bend 180° around a diameter of one thickness. Temperature of the water in which the bar is to be quenched should be about 80° F.

**Blacksmith Grade.**—Minimum tensile strength 45,000 pounds per square inch with minimum yield point of one-half ultimate strength. Minimum elongation, 25%. Minimum contraction area, rounds 40%, flats 35%. Maximum amount of phosphorus, 0.15%. Sulphur, 0.020%. Bending test: Cold, flats 3/8 inch and less around a diameter of two thicknesses, all other material to 180° around a diameter of one thickness. Quenching test: Heat to 1700° F. and bend to same requirements as cold bend. Temperature of the water in which the bar is quenched should be about 80° F.

**Elongation.**—The elongation will be measured in 8 inches with the following exceptions: Flats 1/4 inch and less in thickness will be measured on a length equal to twenty-five times the thickness of the material tested.

On all other material less than 3/4-inch diameter or thickness, the elongation will be measured on a length equal to ten times the diameter or thickness of the material tested.

# STEEL FORGINGS FOR HULLS, ENGINES, AND ORDNANCE

## NAVY DEPARTMENT

1. **General Instructions.**—General Specifications for Inspection of Material issued by the Navy Department shall form a part of these specifications.

2. **Material.**—Forgings referred to herein are to be machined as received from the contractor without reforging or further heat treatment.

The forgings shall conform to sizes and shapes specified by the order.

3. **Process.**—Forgings must be made by the open-hearth or electric process, except Class C, which may be made by the Bessemer process. They must be rolled or forged from ingots, the original cross-section of which is at least four times that of the finished forging.

4. **Discard.**—A sufficient discard shall be taken from each ingot to insure freedom from piping and undue segregation. Such discards shall, unless otherwise approved by the bureau concerned, be not less than 5 per cent from the bottom in any case, 20 per cent from the top, if bottom poured or fluid compressed, and 30 per cent from the top, if top poured.

5. **Surface and Other Defects.**—All forgings shall be free from slag, seams, pipes, flaws, cracks, blow-holes, hard spots, sand, foreign substances, and all other defects affecting their value.

6. **Chemical and Physical Properties.**—The respective classes of forgings shall have the following properties:

| Class | Treatment | Material | Maximum Values | | | Minimum Values | | | | Cold Bend Without Cracking |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Elongation | | |
| | | | C. | S. | P. | Tensile | Yield Point | Long | Trans. | |
| | | | % | % | % | *Lbs.* | *Lbs.* | % | % | |
| Alloy | .. ....... | ....... | 0.45 | 0.040 | 0.04 | 105,000 | 80,000 | 20 | 18 | 180° to inner diam. of 1 in. |
| HG.... | Annealed & oil tempered | Nickel steel | 0.35 | 0.045 | 0.04 | 95,000 | 65,000 | 21 | 18 | Do. |
| An..... | Annealed... | Do. | 0.45 | .045 | .04 | 80,000 | 50,000 | 25 | 21 | Do. |
| Ac..... | Annealed & oil tempered | Carbon steel | .60 | .045 | .04 | 80,000 | 50,000 | 25 | 21 | Do. |
| B-s | Do. optional | Do. | .60 | .045 | .04 | 75,000 | 40,000 | 22 | 19 | Do. |
| B...... | Annealed... | Do. | .40 | .045 | .04 | 60,000 | 30,000 | 30 | 25 | 180° to inner diam. of ½ in. |
| C...... | ........... | Do. | ... | .070 | .07 | 50,000 | ..... | 18 | 15 | ........... |

7. **Nickel steel** shall contain not less than 3 per cent nickel.

8. **Class C forgings** shall not be tested unless there are reasons to doubt that they are of a quality suitable for the purpose for which they are intended.

9. **Physical Test Specimens.**—Test specimens shall, in general, be located during fabrication. Material shall also be provided for possible extra tests. The specimens shall fairly represent the average strength of the material and be taken at a point which has received the average amount of reduction. They should, in general, be located in that part of the forging which includes the top of the ingot as cast, unless otherwise specified or requested by the inspector.

10. **Longitudinal Test Specimens.**—Longitudinal test specimens shall, in general, be taken from a full-sized prolongation of the forging in the direction in which the

metal is most drawn. For forgings with large palms or flanges this prolongation may be of the same cross-section as the part back of the palm or flange. The axis of the longitudinal test specimens shall be located at any point midway between the center and the surface of solid forgings and at any point midway between the inner and outer surface of the wall of hollow forgings.

Prolongations from which test specimens are to be taken shall be left on both ends of each forging.

11. **Transverse Test Specimens.**—When required, or when, for reasons satisfactory to the inspector, it is considered impracticable to obtain longitudinal test specimens, transverse test specimens shall be taken from location selected by the inspector.

12. **Test, Individual, General.**—From forgings of or above 250 pounds completed weight, at least, two tensile and one cold bend test shall be made.

13. **Test, Individual, Special.**—The number and location of test specimens for special forgings weighing when completed 250 pounds or over shall be as listed in table or illustrated on plates.

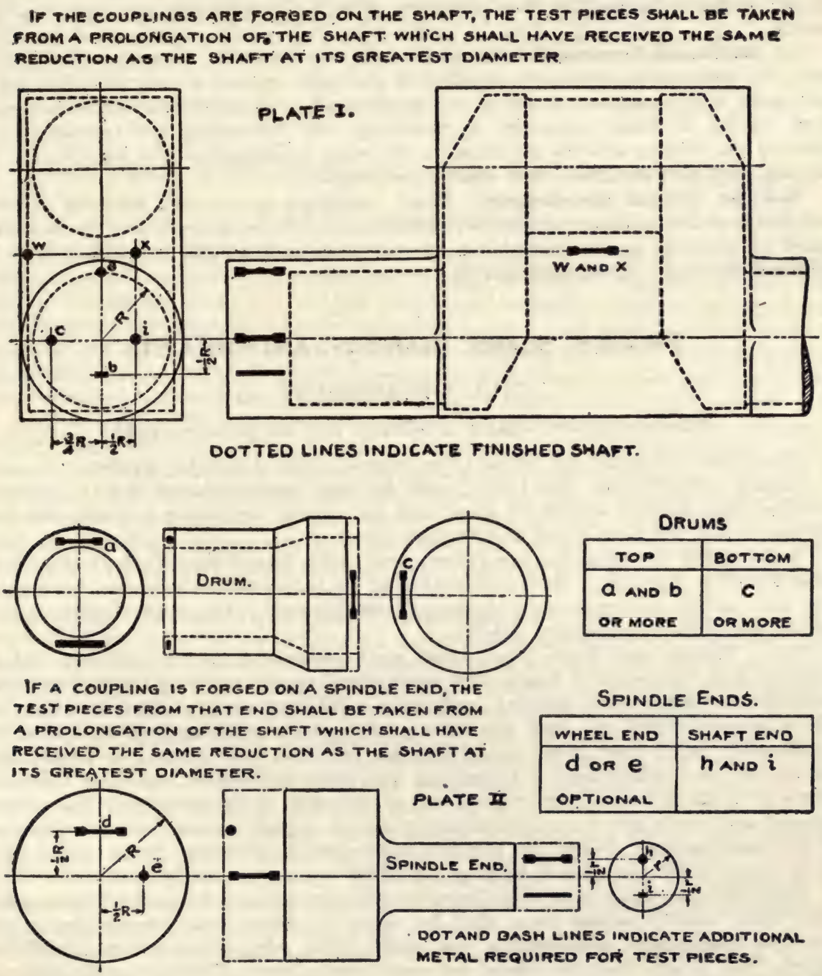
(NOTE.—Letters in the columns of the table indicate the test specimens which shall be taken: "i" inner, "o" outer, "c" center, "W and X" are between the webs; "b" indicates bend specimen. The positions of the test specimens are shown in the plates. One specimen shall be taken for each letter in the column unless otherwise stated. Round sections in the plates indicate tensile bars, square sections bending bars. The letters under "Top," "Bottom," and "Intermediate" indicate the part of ingot to which they apply.) Test specimens for drums and spindle ends shall be located as indicated in Plate II.

| | Top | | | | Bottom | | | | Intermediate |
|---|---|---|---|---|---|---|---|---|---|
| All shafting 10 inches in diameter or over..... | i | o | c | b | i | .. | o | .. | |
| All shafting over 5 inches and under 10 inches in diameter.............................. | i | o | .. | b | i | .. | .. | .. | |
| Shafts, including crank shafts 5 inches in diameter or less......................... | i | .. | .. | b | i | .. | .. | .. | |
| Additional to above for crank shafts over 5 inches in diameter, from one web or crank shaft section............................ | .. | .. | .. | .. | .. | .. | .. | .. | W and X |
| Piston rods, connecting rods, eccentric rods, valve stems, columns, tie-rods, reverse arm blocks and arms, wrist pins, crossheads, valve links, guides, forged bolts and nuts, feathers, keys, collars, sleeves, couplings, and caps................................ | i | .. | .. | b | i | .. | .. | .. | |

NOTE.—For hollow forgings (forged or bored), the inside specimens shall be taken within the finished section prolonged, but as near the positions indicated as possible. See Plates I and II.

14. **Test by Lot.**—Small forgings, including those listed in paragraph 13, weighing less than 250 pounds each as delivered, may be tested in lots of 1,000 pounds or less, the forgings in each lot being of one class and kind only, made from the same melt and heat treated (annealed or oil-tempered) in the same furnace at the same time. In this case the inspector will select at random two tensile and one cold-bending test specimens to represent the lot, each from a different object. When the manufacturer so desires, extra forgings may be made in order to provide for test specimens, which forgings will be selected by the inspector at random from the lot. When small forgings as referred to in the foregoing are not tested by lot the tests made to determine the physical properties thereof shall comply with requirements which may be specified or shall be as directed by the inspector.

15. **Forgings, List of (Partial), Covered by the Foregoing General Requirements.**—Parts of gun recoil system, including recoil and spring cylinders, piston rods; also nuts and bolts for same. Gun elevating and training gear shafts, worms, pinions, keys, and feathers, etc., for same. Parts of gun mount requiring high elastic limit, such as gun yokes, trunnion-bearing caps, floating supports, and other trunnion parts, trunnion bands, and slides. Parts of torpedo tubes and ordnance appurtenances where high elastic limit is required, shafting, rammer, links, etc. Turret rollers, turret-turning pinions, turret racks, and tracks. Armor keys. Holding-down bolts for gun mounts and turret tracks. Rudder frames and rudder stocks. Anchor crane stocks.




16. **Miscellaneous Bars.**—For rolled material not otherwise covered herein, purchased under these specifications, which is not to be reforged, the inspector shall select four tensile and two cold-bending test specimens from each melt of material annealed under the same conditions at the same time. If material is to be reforged, it should not be purchased under these specifications, but under Steel rods and bars for stanchions, davits, and drop and miscellaneous forgings, or Steel ingots, slabs, blooms, and billets.

16½. **Treatment.**—All forgings shall be annealed as a final process, unless otherwise directed. All tempered forgings, if forged solid, and if more than 5 inches in diameter in any part of their lengths, not including collars, palms, or flanges, shall be bored through axially before tempering, and the bore shall be of sufficient size to enable the manufacturer to get the requisite tempering effect. Forgings, such as crank shafts, thrust shafts, etc., may, previous to tempering, be machined in a manner best calculated to insure that the tempering effect reaches the desired portions. In this case the inspector will decide upon the location of the test pieces if they can not be taken in the manner herein described.

17. **Treatment of Hollow Forgings.**—In case of hollow forgings, whenever treatment of any character is specified, this treatment must be given AFTER THE FORGINGS ARE BORED.

18. **Additional Treatment.**—On approval by the inspector, forgings which fail to meet the physical requirements specified in the table, section 6, may be subjected to additional heat treatment to obtain the specified physical properties. Heat treatment shall consist of either annealing or quenching, and tempering, and annealing. All parts of the forging shall be subjected to the same treatment at the same time. No forging shall be submitted more than three times.

**Note for General Storekeepers.**—These specifications are not intended to cover rolled material for ordinary smith use; such material is to be reforged and the annealing called for in these specifications is not necessary and only results in a higher price for common material. (See paragraph 16.)

## INGOTS, SLABS, BLOOMS, AND BILLETS

### NAVY DEPARTMENT

(Rounds shall be classed as billets if they are to be reforged.)

Line between blooms and billets to be drawn at size of 5 inches square.

Ingots, slabs, blooms, and billets made by steel manufacturers, and to be forged or rolled into finished objects by them, will not require inspection or tests; the tests and inspection will be made of the finished objects.

Ingots made by steel manufacturers, and to be forged into finished objects by establishments other than those manufacturing the ingot, will be subjected to chemical test and surface inspection only at place of manufacture. All required physical tests will be made from the finished objects.

Slabs, blooms, and billets from which small objects are to be machined without heating, shall be tested by heats, four longitudinal tensile and four longitudinal cold-bending test pieces being selected, each from a different object; but if less than ten pieces are made from one heat, then two tensile and two cold-bending test pieces will be selected; but if there is but one slab, bloom, or billet from a heat, one longitudinal tensile and one longitudinal cold-bending test piece will suffice, either or both test pieces to be taken from upper or lower end at discretion of the inspector. These slabs, blooms, and billets may be tempered and annealed, or only annealed, at the discretion of the manufacturer, to get the physical requirements, and these requirements shall be the same as for the class of forgings for which the objects are intended.

Slabs, blooms, and billets to be forged into finished objects by establishments other than those manufacturing them shall be tested by heats, four longitudinal tensile and two longitudinal cold-bending test pieces being selected, each from a different object; but, if less than ten pieces are made from a heat, then two tensile and two bending test pieces will suffice. And if there is but one slab, bloom, or billet from a heat, test pieces will be taken as in similar case noted in preceding paragraph. The requirements for slabs, blooms, and billets "for reforging" will be as follows:

High grade or Class A, the same as Class A forgings, except that an elongation of 24 per cent in 2 inches will suffice.

Class B, the same as for Class B forgings, except that an elongation of 24 per cent in 2 inches will suffice.

**Chemical Requirements.**—Billets will be accepted on chemical analysis only and shall be within the requirements of the grade as specified below.

| Grade | C. % | Mn. % | P. % max. | S. % max. | Ni. % min. |
|---|---|---|---|---|---|
| HG | 0.30–0.45 | 0.40–0.80 | 0.04 | 0.045 | 3.0 |
| An | .25– .45 | .40– .80 | .04 | .045 | 3.0 |
| Ac | .40– .60 | .40– .80 | .04 | .045 | ... |
| B-s | .40– .60 | .40– .80 | .04 | .045 | ... |
| B | .25– .40 | .45– .70 | .04 | .045 | ... |
| C | ........ | ........ | .07 | .07 | ... |

# GENERAL REQUIREMENTS FOR ENGINE FORGINGS

## NAVY DEPARTMENT

**Treatment.**—All forgings except those of Class C shall be annealed as a final process unless otherwise directed. All tempered forgings, if forged solid, and if more than 5 inches in diameter in any part of their lengths, not including collars, palms, or flanges, shall be bored through axially before tempering, and the bore shall be of sufficient size to enable the manufacturer to get the requisite tempering effect. Forgings, such as crankshafts, thrust shafts, etc., may, previous to tempering, be machined in a manner best calculated to insure that the tempering effect reaches the desired portions.

**Kind of Ingot.**—The tests herein laid down are adapted to exhibit the qualities of forgings made from the ordinary square, cylindrical, or polygonal ingots cast on end. If ingots are cast in any unusual manner, the amount of the discard from them will be determined by the bureau concerned with a view to leaving the portion to be used at least as good as the metal of an ingot cast in the ordinary way, from which a discard of 30 per cent from the top and 5 per cent from the bottom has been made, or if the ingot is bottom cast, a discard of 20 per cent from the top and 5 per cent from the bottom.

**Test Pieces for Line, Thrust, and Propeller Shafts.**—From each length of rough-forged shaft and from the end which was uppermost in the ingot one tensile-test piece shall be taken at a distance from the center equal to the radius of the finished shaft, and one tensile- and one bending-test piece shall be taken at half that distance from the center. From the other end of the same length of shaft one tensile-test piece shall be taken at a distance from the center equal to half the radius of the finished shaft. If the shaft is 10 or more inches in diameter, three tensile-test pieces shall be taken from the upper end of the shaft and two tensile-test pieces from the other end, the bending-test piece being taken as in the case of the smaller shafts.

In the case of hollow shafting (either forged or bored) the inside pieces shall be taken within the finished section prolonged, but as near as practicable to one-half the finished radius from the center. If the couplings are forged on the shaft the test-pieces shall be taken from a prolongation of the shaft which shall have received the same reduction as the shaft at its greatest diameter.

**Test Pieces for Crankshafts.**—Test pieces from such shafts shall be taken in the same manner and in the same number as described for line, thrust, and propeller shafts. In addition to those test pieces, two test pieces shall be taken from each crank, one from the surface of the metal slotted out and one at a distance of one-half the finished radius of the shaft from the plane, passing through the axis of the shaft and crank-pin, and both taken in a plane perpendicular to that last mentioned and passing through the axis of the ingot. In the case of crankshafts having more than one throw in one forging these test pieces may be taken from one crank only.

Test pieces from piston rods, connecting rods, eccentric rods, valve stems, columns, tie-rods, wrist pins, crossheads, valve links, guides, forged bolts and nuts, feathers,

keys, collars, sleeves, couplings, and caps: one longitudinal tensile-test piece shall be taken from the prolongation of one end of the heads or ends of the rough-forged rod stem, etc., and one longitudinal cold-bending test piece shall be taken from the prolongation at the other end. If, however, the single rough forging weighs less than 100 pounds, the forgings may be tested in lots of 1,000 pounds or less, the pieces in each lot being one kind only, made from the same heat and annealed in the same furnace at the same time.

**Test Pieces from Reverse Shafts.**—If the shaft is 5 inches or less in diameter one longitudinal tensile-test piece shall be taken from one end and one longitudinal cold-bending test piece shall be taken from the other end. If the shaft is over 5 inches in diameter, one tensile- and one cold-bending test piece shall be taken from the end which was uppermost in the ingot, and one tensile-test piece from the other end.

## ENGINE FORGINGS

H. F. J. Porter

Having carefully considered the service to which a proposed forging is to be put, the charge of raw material for the furnace is so made up that the finished product will have the proper chemical composition, which, from previous experience, is found to be most satisfactory.

**Furnace.**—The product of the open-hearth furnace is found to give eminent satisfaction, and has been generally adopted for making steel forgings.

**Size of Ingot.**—In order that the metal of a forging should be thoroughly worked to give it strength and toughness, an ingot should be cast approximately 50 per cent. larger in diameter than the finished size. Besides this increase there should be from 10 to 25 per cent added to its length, for reasons which will become apparent.

**Defects.**—Various defects are inherent in steel ingots, as: (1) When pouring metal into the mold, air is apt to be entrained and cause " blow-holes." (2) At certain stages of the cooling process gas is generated, which will also cause blow-holes. There are several ways of overcoming these two defects; the most efficient is the Whitworth process of fluid compression, in which the mold, when filled with molten steel, is run underneath a hydraulic press, which should have a capacity of over 7,000 tons; under this enormous pressure the air entrained in the pouring is forced out through joints in the mold, vents having been left for that purpose, and the gases which are apt to form in the cooling of the mass are prevented from generating.

**Piping.**—This defect is apt to occur in an ingot, since the metal poured into a mold cools and solidifies first at its surface; as the solid metal keeps cooling toward the center, it shrinks and draws away from it. This shrinkage draws principally from the center and from the top, as these solidify last; to take care of this shrinkage, more metal is added to the length of the ingot than would otherwise be required. The hydraulic pressure applied at the top forces fluid metal from this added part down through the center of the ingot, supplying the latter with fluid steel where, otherwise, there would be formed a cavity or "pipe."

**Segregation.**—This defect is apt to occur in ingots of very large size. It is partly a mechanical and partly a chemical separation of the various ingredients of steel (sulphur, phosphorus, manganese, silicon, etc.), each of which has its own temperature of cooling. As the mass cools the tendency of these ingredients is to seek the central and upper portions which cool last, thus forming a central core of impurities. This does not occur to great extent in small ingots; in all large ingots it does occur, and fluid compression does not entirely prevent it. But compression does succeed in producing perfectly solid steel, and the defect of " segregation " in large ingots is otherwise taken care of, as will be explained. It is necessary to have an absolutely solid ingot at the beginning, because steel will not weld, if there are defects in the ingot to start with, they cannot be remedied later by hammering. The extra length of ingot having served its purpose of supplying metal to fill blow-holes and pipes, and collecting segregation, is then cut off and returned to scrap. The ingot is then ready for the forging process.

**Reheating the Ingot.**—This operation is a delicate one, as great care must be taken

to make the heat penetrate the metal slowly and uniformly. The cold ingot is in a condition of strain throughout its interior; if put into a hot furnace to be reheated, its surface would immediately expand and an additional strain would be put on the inside metal. In very large ingots cracks are thus apt to be started in the center and forgings are liable to break in subsequent service.

**Recalescence.**—If the rate of cooling of a steel ingot from the point of solidification to coldness is carefully noted, it will be seen that the temperature falls with regular retardation in equal divisions of time until, between 1000 and 1200° F., a point (depending on the carbon content) is reached where it suddenly stops and for a time either remains stationary or perhaps rises for a short time, and then the same rate of cooling continues as before. This point, where the change of rate takes place, is called the "recalescent" point, and from chemical and physical tests it is known that a change in the structure of the steel occurs here. The fluid steel begins to crystallize at the point of solidification, and the slower the rate of cooling from there down the larger the crystals will be when the ingot is cold. At the point of recalescence, however, it would seem as if the crystallization, so to say, locks itself, for, if after the ingot has become cold it is reheated to a temperature below this point, on again becoming cold it will be found that the crystallization is not affected, but if reheated a little above the recalescent point, when it is again cold, the crystallization will be found to be much smaller than before. If steel is heated slightly above the recalescent point all previous crystallization is destroyed, and a fine amorphous condition is produced at that temperature. As soon as cooling begins again crystallization sets in, and continues until the ingot is cold. As, however, the time of cooling from the recalescent point is comparatively short, the resultant crystallization is correspondingly small.

**Forging.**—Certain changes take place in the condition of the metal as it passes through the forging process. Beginning with the cold ingot which, having cooled slowly, is therefore composed of large crystals, it must be reheated to a forging temperature of from 1800 to 2000° F., thus passing through the recalescent point, destroying all crystallization and producing an amorphous condition. As soon as it is placed under the forging press it begins to cool, crystallization at once setting in; at the same time, however, the press begins to work upon it. The pressure applied in shaping a piece of steel should be sufficient in amount and of such a character as to penetrate to the center and cause flowing throughout the mass. This flowing of the metal requires a certain amount of time, and the requisite pressure should be maintained throughout a corresponding period. The hydraulic press fills these requirements exactly. Under the slow motion of the press time is allowed for the molecules of the metal to move easily, and the pressure is felt throughout the forging. The center being the hottest, and therefore softest, is squeezed out, and gives a convex shape to the end of a forging.

The work of forging tends to check crystallization just as disturbing water which is below freezing point will delay the formation of ice crystals. The work of forging may or may not continue (depending upon the size and shape of the finished piece) until the temperature has fallen below the recalescent point, but during this time more or less crystallization has occurred, and has been disturbed and distorted. The work of forging has, moreover, proceeded from one end of the piece to the other, the part last worked upon having crystallized considerably before work was applied to it, so that the two ends may be entirely different as far as their internal condition is concerned.

In order that the metal should be worked at the proper temperature, it is necessary to reheat it a number of times, and every time the press descends upon the metal, the latter is worked under conditions differing from those existing when the press descended upon it. This character of heat treatment is called "oil tempering," and should be followed by a mild annealing heat treatment to relieve the metal of any hardening effect due to the cooling process.

**Hollow Forgings.**—In order to successfully temper a piece of steel, great care must be taken both in the process of reheating it and also in cooling it in the bath. In reheating it, the surface metal is apt to expand away from the center and thus cause cracks in the latter, and in dropping it into the cold bath the surface metal is apt to contract on the center to such an extent as to cause cracks in the former. In order, therefore, to successfully temper a forging, it should be hollow. By taking out the

center it can be reheated without danger of cracking, because the center metal is absent and the heat gets into the interior and expands both it and exterior together.

Also in dropping it into the cold bath there is no solid center on which the metal is contracted, and in that way the danger of cracking during the cooling process is eliminated.

There are two ways of making a forging hollow. The ordinary way of getting rid of the center of a forging is simply to bore it out. After boring, it is tempered, and thus the strength is restored which was taken away with the material which was in the center.

Another way of getting rid of the center of large forgings is to forge them hollow. A person who has not considered the subject carefully would naturally think that the first thing to do in making a hollow forging would be to cast a hollow ingot. It has been mentioned that there are various defects which occur in ingots, the most serious of which are segregation and piping, and that it is in the center and upper portion where those defects occur. If an ingot were to be cast hollow a solid core of fire-brick or similar material would replace the center metal, and instead of one on the outside there would be two cooling surfaces, one on the outside and one around the core, and the position of last cooling would be transferred to an annular ring midway between these surfaces where the piping and the segregation would collect. This would not be satisfactory, because the metal there is what must be depended upon for the strength of the hollow forging. It is necessary, therefore, to collect the piping and segregation in the center and at the top, where metal has been added to the original ingot for the purpose.

After the hole has been bored in the ingot, the next process is to reheat it; this process is not as delicate as if the ingot were solid, because the heat affects the center equally with the exterior, and as the two expand together the danger of cracking is not incurred. When the ingot is reheated a steel mandrel is put through its hollow center, and subjecting the two to hydraulic pressure, the metal is forced down and out over the mandrel. Thus an internal anvil is practically inserted into the forging, and there is, therefore, really much less than one-half the amount of metal to work on than if the piece were solid.

When the work of shaping is completed the forging is reheated to the proper temperature and then either annealed in the usual manner or plunged into a tempering bath of oil or brine to set the fine grain permanently that has been established by the reheating. A mild annealing follows to relieve any surface or other strains that may have been occasioned by the rapid cooling.

## BELL STEAM HAMMER

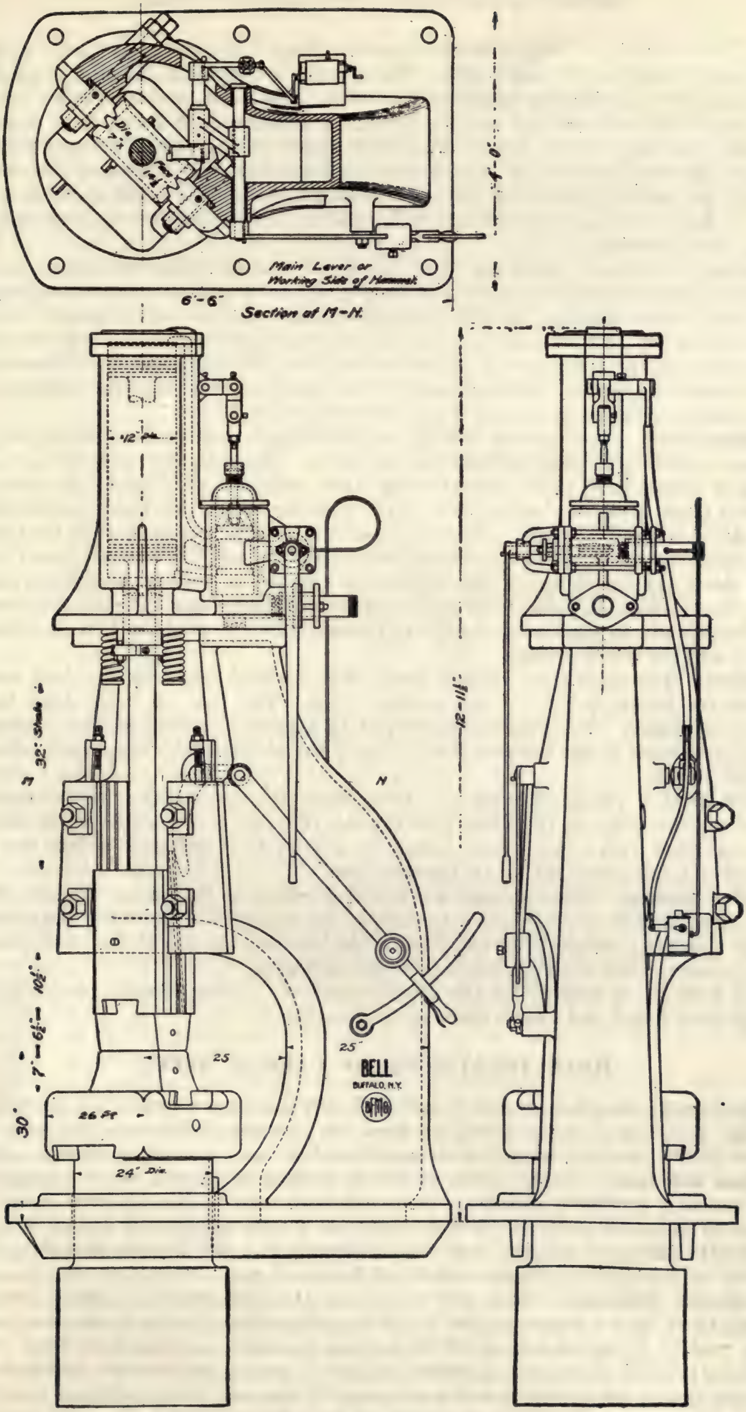
The hammer shown on the opposite page, designed by David Bell, is rated at 1500 pounds, which represents the weight of the falling parts. The general proportions are clearly shown and these are further supplemented by leading dimensions.

**Operation.**—This hammer is double acting, taking steam at top and bottom of stroke through ports arranged to give maximum force to the blow. Control is maintained by the operator either by hand operation of the main lever, or a continuously sustained automatic action is obtained, with close and sensitive regulation, by operation of the throttle valve lever, with the main lever stationary on its quadrant.

**Valve Motion.**—The valve motion is of few working parts and these are so designed as to give accurate and sensitive control to the blow. The main operating valve is of the vertical piston type, its motion is obtained by sliding contact of a cam against a beveled path formed by the surface of a removable plate attached to the back of the hammer head. The downward movement of the piston valve is by gravity alone; the upward movement is by the thrust of the cam plate in sliding contact against the cam. This construction eliminates positive connections in the valve gear; the sliding contact prevents any shock or jar from the blow being transmitted to the valve gear parts.

The column of this hammer is cast solid with its bed plate; the latter is provided with heavy vertical ribs cast on its under side.

**Cylinder.**—The cylinder, and its piston valve and throttle valve chests, are in-




Bell Steam Hammer
Buffalo Foundry & Machine Co., Buffalo, N. Y.

cluded in one casting. The cylinder is heavily flanged at top and bottom, the latter flange being reinforced by heavy ribs. The cylinder is dowel pinned and secured to the main frame by through-going machine fitted bolts. The steam ports cast in the cylinders are of ample size and arranged to give, through the operation of the valves, a maximum efficiency and force to the blow. The lower steam port slopes downward from the cylinder allowing the water of condensation to drain from the bottom of the cylinder through the piston valve chest into the exhaust pipe outlet, which is always lower than the bottom of the cylinder and valve chest. This automatic drainage prevents damage from freezing.

**Valves.**—The main operating valve is of the vertical balanced piston type, it operates without friction due to steam pressure, and gives sensitive control in operation. The piston valve bushing has the steam port edges finished so as to give accurate admission, cut-off, and exhaust points in the movement of the valve. Reference marks are provided on the upper end of the valve stem, that the valve may be adjusted without disconnecting any of the other parts of the hammer. The throttle valve is of the plain circular or rolling type opened and closed by a hand lever.

**Falling Parts.**—The hammer head is an open-hearth steel forging, hammered from the ingot or billet and then finished from the solid. The piston rod and head is a single forging of open-hearth steel, or heat treated and annealed alloy steel. Its lower end is turned taper to fit the tapered hole in the hammer head; this taper constitutes the real hold of the rod in place. There is, however, a safety pin to prevent the hammer head falling, in the event of its coming loose from the rod. The piston head can be raised above the top flange of the cylinder to examine or replace the piston packing rings; to do which, it is not necessary to disconnect the piston rod from the hammer head, but simply to remove the piston rod gland (which is made in halves, bolted together), and the buffer springs.

**Guides.**—The guides are of cast iron; this material possesses the best wearing qualities for sliding contact of the hammer head. The face of these slides has accurately machined " V " projections scraped to a perfect bearing surface corresponding to the recesses in the hammer head. Slides are adjustable by taper keys extending their full length.

**Anvil Block.**—The anvil block is in two pieces; the upper part is easily removable to give additional space, the lower part extends through a cored hole in the bedplate and is provided with a heavy base resting on a separate foundation, so that the jar of the blow is not transmitted to the hammer itself.

**Buffer Springs.**—Spiral springs are fastened either to the under side of cylinder flange, or to the top of the cylinder, to cushion the up stroke, to prevent injury through careless handling; ample clearance is provided between the top of the piston and the cylinder cover, when these springs are compressed solid.

This hammer is suitable for the heavier class of blacksmith work, and will make forgings from round and square stock up to 6 inches.

## HEAT TREATMENT OF CARBON STEEL

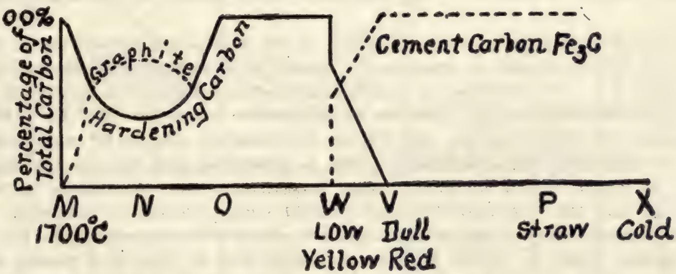
The quantity of carbon present in tool steels will vary from about 0.70% for such tools as sledge hammers to about 1.25% for taps, dies, reamers, lathe tools, etc.; the intermediate grades are very numerous to supply real or fancied needs in shop practice.

**Carbon and Iron.**—Carbon exists in iron in at least two forms, (1) as cementite, or $Fe_3C$, which is a definite carbide of iron, and is the non-hardening form in which it appears in annealed steel; (2) as martensite, or a solid solution of carbon in iron, a hard brittle substance varying in its characteristics with the amount of carbon. It is the chief constituent in suddenly cooled and hardened steel.

**Molecular Structure.**—This will vary with the percentage of carbon, the temperature to which it is subjected, and to the rate of cooling, whether slowly as in annealing or rapidly as in quenching. The leading crystalline groups have been named cementite, pearlite, martensite, austenite, troostite, sorbite, etc., but the two important molecular groups are cementite and martensite. Cementite is the carbide of iron, $Fe_3C$; when it is distributed uniformly in minute crystals throughout the iron, its fracture is

clean; it strengthens and hardens the mass. Martensite is the chief constituent in suddenly cooled and hardened steel. It is thought possible that ferrite and cementite unite to form martensite when the steel is highly heated, and the structure is retained when the steel is rapidly quenched. Professor Arnold's view is that martensite is not a constituent, but a crystalline structure developed at high temperatures. Austenite is obtained by quenching steel containing from 1.1% to 1.6% of carbon, from 1000° C. (1832° F.) in ice brine. It is not so hard as martensite, can be machined, and is non-magnetic.

**Tempering and Annealing.**—The effect of temperature on the condition of carbon is shown in the accompanying diagram after Howe, indicating the influence of temperature on the tendencies to form graphite, hardening, and cement carbon. The graphite-forming tendencies are at a maximum at N, or at a white heat. The tendency to form cement carbon is at a temperature of dull redness; and the tendencies to form hardening carbon seem to reach two corresponding distinct maxima, one at above a white heat N, and the other at a low yellow heat, the W of Brinnell. The tendency to form graphite is confined to the range of temperature represented between the points




M and O, and, if steel be kept for a long period at the temperature N, it becomes coarse-grained, due to the crystallization both of graphite and of the iron. The crystalline structure of steel is generally unfavorable from the point of view of its industrial use, but this structure may be broken by the mechanical work of forging the steel while hot; but, if the forging be continued below the point V, the iron is then in a different state and will possess different properties.

In annealed steel, practically all the carbon is in the cement state unless the annealing temperature has been too high, so as to approach the temperature represented by the point N. Moreover, at the point W, and up to the point O, the cement carbon is in solution in the iron, and, if suddenly cooled, will remain in what has been conveniently termed the hardening carbon state. On the other hand, if the steel has been gradually cooled to below the point V, the hardening carbon will be changed to cement carbon. At a temperature between W and V, iron undergoes a sudden expansion, and its thermo-electric behavior is abnormal. Also a change in its magnetic properties is observed.

Reheating hardened steel to P, a straw color appears on the brightened surface, which passes to a deep straw, a purple, a blue, and finally a black as the temperature is gradually raised, all the above temperatures being below the point V, at which the carbon passes into the cement form on slow cooling, or into the hardening or solution form on heating up. Now the question arises, Does the hardening carbon, in hardened steel, pass partially into the cement form during this tempering process? Howe considers that, while the tendency exists, it is held in check by what may be termed chemical inertia or viscosity. That as the temperature rises to a straw heat this viscosity is released and some of the carbon passes into the cement state, and the steel is therefore softened. At a blue heat still more of this change occurs. This harmonizes with the fact that while hardened steel is softened by reheating, annealed steel is not hardened by being quenched below V. Hence below this point the cement state is permanent.

**Elements Other than Carbon.**—Carbon tool steels contain slight percentages of silicon, manganese, sulphur, and phosphorus. Silicon and manganese, being useful constituents, give improved fusing and working qualities, together with increased

ductility and resistance to shocks. Silicon and manganese exert some influence on the hardening properties of steel. Sulphur and phosphorus are impurities, and affect the toughness of the material, phosphorus tending to make the steel cold-short or brittle, and sulphur making it red-short or difficult to forge.

**Carbon Theory of Hardening Steel.**—Carbon steel is essentially iron and carbon, each element contributing a well-defined constitution, and characteristic structure. Pure iron has a definite freezing point, about 1600° C. (2912° F.). Carbon is practically infusible; it therefore maintains separate existence, but its action is limited to the influence it exerts upon the iron. In pig iron carbon is present in both the graphitic and combined states; in steel the carbon is combined with the iron; for this reason steel is often termed an alloy of iron and carbon; there is also a close analogy to that class of compounds termed solutions.

Highly carburized steel, if long exposed to a sufficiently high temperature while cooling, will contain graphite crystals in addition to its chemically combined carbon, but if the steel be cooled rapidly as in quenching, no graphite crystals are formed; the whole of the carbon continues in the combined state, giving to steel the quality of hardness.

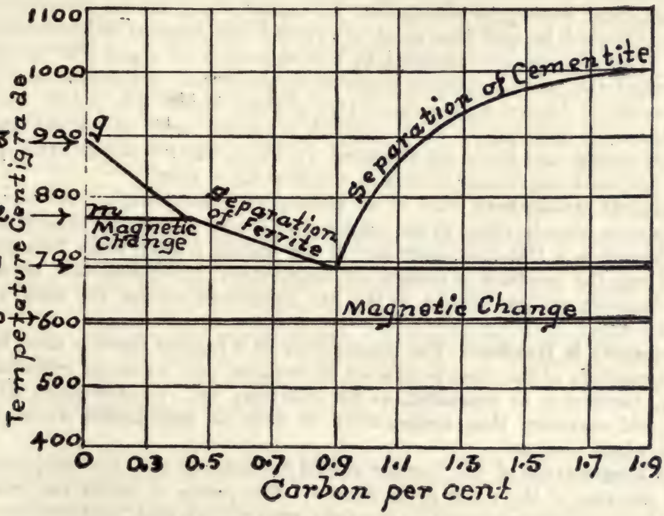
The carbon in steel changes form suddenly at the critical temperature. If the steel contains about 0.90% carbon it remains unchanged in structure until heated to about 738° C. (1360° F.). An increase in temperature beyond this point causes the ferrite and pearlite to decompose; the reaction is completed at about 793° C. (1460° F.), which is called the critical point; the ferrite and pearlite change to martensite. By quenching at this point the martensite grain is preserved and the steel is hardened. If the steel be again heated to a still higher temperature the martensite in turn will be decomposed and the original ferrite and pearlite condition will be restored.

**Solution Theory.**—In the case of pure iron in a state of fusion, cooling to the solidification point, say, 1600° C. (2912° F.), the solidified iron is then in a plastic state, to which the name of "gamma" iron has been given by Osmond. While it is in this form it is capable of dissolving about 0.90% of carbon at 900° C. (1652° F.), and rather more at higher temperatures. At 1000° C. (1832° F.) it dissolves 1.50% carbon. When pure gamma iron cools to 890° C. (1634° F.), it undergoes a change to another allotropic form, known as "beta" iron, and this change is accompanied by a considerable evolution of heat. This beta iron, like the gamma modification, is non-magnetic, but it is less capable of holding carbon in solid solution than gamma iron. As the iron cools down to 770° C. (1418° F.), another molecular change occurs and the beta iron changes to what is termed "alpha" iron, which is magnetic. Much heat is evolved, but less suddenly than at the previous change, probably because the iron is less mobile at the lower temperature. As beta iron dissolves less than 0.10% carbon, the influence of carbon upon iron is practically eliminated at temperatures below the point of change from gamma to beta iron. When the metal cools down to about 610° C. (1130° F.) another critical point is reached, which appears to be the beginning of a slight molecular change extending over a range of 100° C. (212° F) and is accompanied by a change in magnetic properties.

**Allotropic Theory of Hardening.**—The general acceptance of this theory is based upon results obtained in investigations on the cooling of steel. It is known that molecular change is accompanied with evolution or absorption of heat; if now a bar of unhardened steel be heated to, say, 500° C. (932° F.) and allowed slowly to cool, no break in the uniformity of cooling occurs; but if the steel be heated to 900° C. (1652° F.), or even 750° C. (1382° F.), there are stages where the cooling is arrested. This is due to some molecular change in the steel that produces heat. Osmond observed that the effects of cold working and quenching from a high temperature were somewhat similar, and concluded that they must arise from a common cause. He supposes that the condition of the carbon is not changed by cold working, and therefore the hardening effect is due to an allotropic effect in the iron itself. Although the presence of carbon is essential to the hardening of steel, the change in the mode of existence of the carbon is less important than was formerly supposed. Howe suggests that it is the hard, strong, brittle beta modification of the iron that causes hardening, and that the carbon simply acts in retarding the change from hard beta to soft alpha iron. One argument in

favor of allotropy is the sudden disappearance of magnetic properties on heating caused by the sudden change of specific heat, and the spontaneous retardations that occur in cooling practically carbonless iron.

The three critical points which occur on cooling a piece of very mild steel from a temperature of 1000° C. (1832° F.) are shown in the accompanying diagram. According to Osmond these are: (1) A slight evolution of heat at about 890° C. (1634° F.), termed $Ar_3$. (2) A disengagement of heat at about 765° C. (1409° F.), termed $Ar_2$. (3) Another point at about 690° C. (1264° F.), small in very mild steel and highly accentuated in steels high in carbon, termed $Ar_1$.




In pure iron, on cooling from 1000° C. (1832° F.), when the iron is in the **gamma** state, an evolution of heat is observed at 895° C. (1643° F.), (the point $Ar_3$) when the iron is said to change from the **gamma** to the **beta** form. Another change occurs in very mild steel at 765° C. (1409° F.), after which the iron is said to be in the **alpha** form. The presence of dissolved cementite lowers the temperature at which these changes occur.

In steel containing less than 0.30% carbon, in which the points $Ar_3$ and $Ar_2$ both occur, the formation of beta iron from gamma iron occurs at points differing with the content of carbon. Iron in the gamma form will dissolve about 1.00% carbon as cementite, at about 890° C. (1634° F.), but beta iron will scarcely dissolve any carbon, so that the beta iron, being practically free from combined carbon, undergoes the change to alpha iron at the normal temperature of 765° C. (1409° F.). Meanwhile, as the iron falls out, the residual solution becomes richer in cementite, until at 690° C. (1274° F.) it is saturated, forming an eutectic solid solution, and the cementite and iron (in the alpha form) separate out, side by side, to form the well-known "pearlite." The evolution of heat at 690° C. (1274° F.) marks the point known as $Ar_1$.

If the steel contains 0.34% of the carbon the point $Ar_3$ occurs at the same temperature as $Ar_2$, and further additions of carbon result in the lowering of the temperature of the combined point $Ar_{2-3}$. In such steels the excess of iron separates out in the alpha form, and the residual solid solution is decomposed as before at the point $Ar_1$ 690° C. (1274° F.).

**Sorbite.**—This is a transition form, passing into pearlite, intermediate between troostite and pearlite, probably having the composition $Fe_9C_3$, and existing in a solution of iron. It may be simply unsegregated pearlite. Sorbite is obtained by a moderately slow cooling, as in the cooling of small samples in air. Also by quenching in water at the end of the recalescence period.

**Heating Carbon Steel.**—The first effect of heat upon a piece of steel is a physical one, consisting principally in an increase of size, possibly a change in shape through mechanical strains which occur in its structure; these changes are not great even when the steel is hot, they largely but not wholly disappear upon cooling.

Chemical changes take place in steel by altering the condition of the carbon when the temperature is raised sufficiently high; the greater the percentage of carbon, the more fusible the steel and the more easily overheated. When a piece of steel, hardened or unhardened, is heated up to a low-yellow heat, about 996° C. (1825° F.), all previous crystallization, however coarse, is obliterated and replaced by the finest structure the metal is capable of assuming. Steel containing 0.90% carbon remains unchanged in structure until heated to about 738° C. (1360° F.). As the temperature of the furnace is increased beyond this point the ferrite and pearlite suddenly begin to decompose. The reaction is completed at a temperature of about 790° C. (1460° F.), which is called the critical point or point of recalescence. To obtain the best results the steel must be heated to a temperature slightly above this point. Otherwise it fails to harden on quenching. If the heating is carried much above the critical point the grain is coarser and there are increased weakness and brittleness after quenching.

There are three important factors in the heating of steel:

1. **A neutral atmosphere,** that is, an atmosphere containing no free oxygen. Particular attention must be given to the thickness of the fire; steel of whatever kind should never be heated in a thin fire, especially in one having a force blast, because more air passes through the fire than is needed for combustion; in consequence, there is a considerable quantity of free oxygen in the fire which will oxidize the steel, or in other words, burn it.

2. **Uniformity in Heating.**—The temperature of a heating furnace must be adjusted to the composition of the steel in process of working, and a further adjustment suited to forging, hardening, or annealing, as the case may be. Each requires its own temperature, and whatever that temperature, it must be maintained without variation during the whole process.

3. **The temperature** of the furnace should be fixed to suit the composition of the steel and the size of the piece to be heated. For pieces in which the section is not uniform, the temperature should be carefully graded, as a high heat produces a coarse, open grain, and irregularity of heating is likely to cause cracking from internal strain. Any difference in temperature sufficiently great to be seen by color will cause a corresponding difference in the grain. Any temperature so high as to open the grain so that a hardened piece will be coarser than the original bar will cause the hardened piece to brittle. A temperature high enough to cause the piece to harden through, but not enough to open the grain, will cause the piece to refine, to be stronger than the untempered bar. A temperature which will harden and refine the corners and edges of a bar but will not harden the bar through is just the right heat at which to harden taps and complicated cutters of any shape, as it will harden the teeth sufficiently without risk of cracking and will leave the mass of the tool soft and tough.

**Carbon Tool Steel.**—An outline of the proper grades and tempers of carbon tool steel for various uses by Mr. W. B. Sullivan, together with suggestions as to heat treatment, is summarized below:

Grade A steel containing 1.00 to 1.15% carbon is used for lathe tools, taps, dies, and reamers. Steel with a carbon content of 1.15 to 1.25% is recommended for brass tools, finishing tools, and machine-shop small tools. Heating temperature should not exceed 927° C. (1700° F.), a bright cherry to salmon color, for forging. This steel hardens at 793° C. (1460° F.), a light cherry red. The temper should be drawn to suit the character of the work, annealing temperature from 705° to 732° C. (1300 to 1350° F.) corresponding to a full cherry red.

Grade B steel containing 0.90 to 1.00% carbon is used for shear blades, and punching tools. Steel with a carbon content 1.00 to 1.15% carbon is used for machine drills, counter bores, milling cutters, and general machine-shop tools. Heating temperature should not exceed 955° C. (1750° F.), a light orange color, for forging. This steel hardens at 796° C. (1465° F.), a light cherry red. The temper should be drawn to

suit the character of the work, annealing temperature from 705 to 732° C. (1300 to 1350° F.) corresponding to a full cherry red.

Grade C steel for sledges and hammers should contain 0.70 to 0.80% carbon. Heating temperature should not exceed 960° C. (1800° F.), a yellow color inclining to a light orange, for forging. This steel hardens at 807° C. (1485° F.), a light cherry red. The temper should be drawn to suit the character of the work, annealing temperature from 705 to 732° C. (1300 to 1350° F.) corresponding to a full cherry red.

Grade C steel for smith tools, track tools, and boiler-makers' tools, should contain 0.80 to 0.90% carbon. Heat treatment same as above.

Grade C steel for cold chisels, hot chisels, and rock drills, should contain 0.90 to 1.00% carbon. Heating temperature should not exceed 955° C. (1750° F.), a light orange color, for forging. This steel hardens at 796° C. (1465° F.), a light cherry red. The temper should be drawn to suit the character of the work, annealing temperature from 705 to 732° C. (1300 to 1350° F.) corresponding to a full cherry red.

Grade D steel containing 0.70 to 0.80% carbon is used for crow bars, pinch-bars, pickpoints, and wrenches. Heating temperature should not exceed 960° C. (1800° F.), a yellow color inclining to a light orange, for forging. This steel hardens at 807° C. (1485° F.), a light cherry red. The temper should be drawn to suit the character of the work, annealing temperature from 705 to 732° C. (1300 to 1350° F.) corresponding to a full cherry red.

The hardness of a piece of steel properly treated is governed by the size, character of steel, temperature of bath, and character of bath. In general, for small sections lower temperatures should be used than for large pieces. The degree of hardness depends on the rapidity with which the heat is extracted from the steel. A bath of high temperature will produce less hardness. A piece of steel quenched in water will be harder than one quenched in oil. Tests made by the Carpenter Steel Company showed that, compared with water on a basis of unity No. 1, mineral oil had a tempering quality of 0.241; cottonseed oil, 0.161; fish oil, 0.149.

COLOR SCALE INDICATING TEMPER OF CARBON STEEL TOOLS

| Colors Indicating Temper Drawn After Hardening | | | | Composition and Temperatures of Molten Alloys of Lead and Tin | | | |
|---|---|---|---|---|---|---|---|
| Cent. Deg. | Fahr. Deg. | Temper Color | Suitable for | Parts of Lead | Parts of Tin | Fahr. Deg. | Cent Deg. |
| 221 | 430 | Pale yellow | A | 15 | 8 | 430 | 221 |
| 227 | 440 | Light yellow | | 16 | 8 | 440 | 221 |
| 232 | 450 | Pale straw-yellow | | 17 | 8 | 450 | 232 |
| 238 | 460 | Straw yellow | B | 19 | 8 | 460 | 238 |
| 243 | 470 | Deep straw-yellow | | 21 | 8 | 470 | 243 |
| 249 | 480 | Dark yellow | | 24 | 8 | 480 | 249 |
| 254 | 490 | Yellow brown | | 28 | 8 | 490 | 254 |
| 260 | 500 | Brown yellow | C | 33 | 8 | 500 | 260 |
| 266 | 510 | Spotted red-brown | | 39 | 8 | 510 | 266 |
| 271 | 520 | Brown purple | | 48 | 8 | 520 | 271 |
| 277 | 530 | Light purple | D | 60 | 8 | 530 | 277 |
| 282 | 540 | Full purple | | 75 | 8 | 540 | 282 |
| 288 | 550 | Dark purple | E | 100 | 8 | 550 | 288 |
| 293 | 560 | Full blue | | 200 | 8 | 560 | 293 |

A. Suitable for: Lathe and planer tools. Profile cutters for milking machines. Slight turning tools. Scrapers for brass. Hammer faces.

B. Suitable for: Milling cutters. Taps and screw cutting dies. Reamers. Boring cutters. Hollow mills. Counter bores. Punches and dies. Wire-drawing dies. Thread chasers. Planing and molding-machine cutters. Inserted saw teeth. Rock drills. Stone-cutting tools.

C. Suitable for: Twist drills. Flat drills for brass. Drifts. Wood-boring cutters. Gouges. Hand-plane irons.

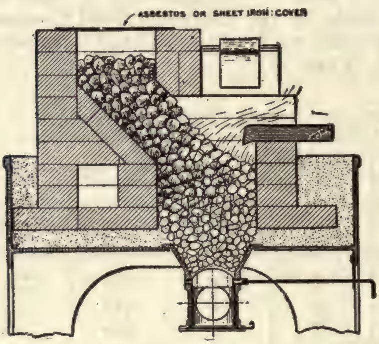
D. Suitable for: Cold chisels for steel. Axes. Augers.

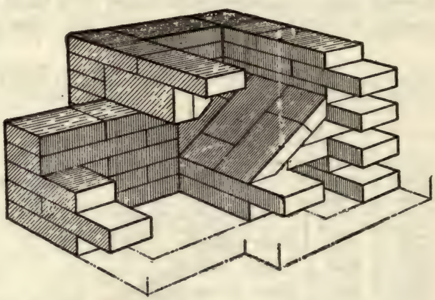
E. Suitable for: Cold chisels for wrought and cast iron. Circular saws for metal. Hack saws. Springs. Molding cutters for wood. Circular saws for wood. Woodworking chisels.

## FURNACES

Furnaces for heating, hardening, tempering or annealing steel are made for the use of coke, oil, gas and electricity. A coke furnace recommended by Mr. R. H. Probert, so simple that a sketch is not needed, has proportions as follows: The inside of the furnace proper should be 36 × 60 inches with a door 12 inches high by 24 inches wide; ash space about 24 inches high and 32 inches wide; grate bars of cast iron, with ½-inch openings, giving an evenly distributed supply of air to the fuel, which should be hard coke, about the size of a hen's egg. In the clear flame of a coke fire, the whole interior of a furnace can be seen easily.

**Tool Tempering Furnace.**—A tool tempering furnace which can be built with about one hundred standard fire-bricks on any tool temperer's forge is here shown. The advantages of the type of fire obtained with this furnace, as compared with the ordinary forge fire, are, that it gives the three most important qualities of a good tempering fire: First, a deep permanent fire; secondly, an intensely hot fire, when wanted; and thirdly, a fire in which it is possible to get a very short heat on a tool, the high heat extending only to the cutting edge or nose of the tool.



As shown in the sectional view, the fire is deep below the nose of the tool, and does not burn out, as new fuel constantly works down from the hopper. This insures a good heat continuously, so that tool after tool, or two or three at a time, may be tempered at a high heat without placing them in contact with the coals.

By resting the tool on a fire-brick with the cutting edge down, a heat is obtained just where it is wanted, that is, on the cutting edge, and at the same time the heat is confined to the nose of the tool. For fuel, either coke or hard coal may be used to advantage.

**Muffle Furnaces.**—In this type of furnace a separate vessel is heated usually by means of a coal or coke fire located underneath the muffle, the products of combustion being made to circulate around it with rotary motion, thus distributing the heat evenly throughout the inclosed space. The work is not heated by contact with or radiation from the flame, but by radiation from the hot walls of the muffle. For certain classes of work, such as taps, dies, reamers, milling cutters, etc., where it is desired that the work be wholly separated from the products of combustion, this type of furnace is commonly used.

**Oven Furnaces.**—This type of furnace in which oil or gas is used for fuel is largely displacing the muffle furnace in which coal or coke is used as fuel. Muffles were then necessary to keep the products of combustion from coming in contact with the steel

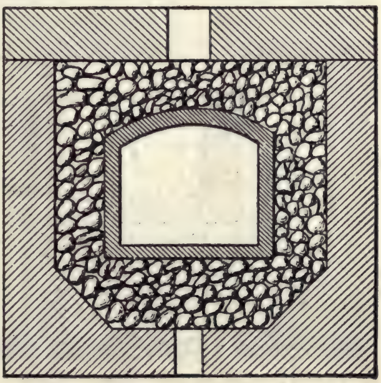
under treatment, these products being injurious to hot steel. In the modern oven furnace using gas or oil as fuel these injurious gases do not come in contact with the work; instead of a muffle the furnace is equipped with a U-shaped bottom slab, having extensions up the sides about 1½ inches high; these sides prevent the flame from coming in direct contact with the work.

**Oil Furnaces.**—(1) To begin with, oil fuel does not burn as a liquid. It first passes into the condition of a vapor. (2) This vapor cannot burn without mixture with air. (3) A suitable temperature for combustion must be maintained. Means for vaporizing the oil, for insuring an adequate air supply, and for producing an intimate mixture within a chamber kept at a suitable temperature, lie at the foundation of all methods of oil burning.

The conditions favoring vaporization are fine subdivision; that is, the production of a large surface for a given weight, together with high temperature. Both of these are fulfilled by breaking the oil up into a fine spray and forcing it into the furnace in this condition. When the spraying is done by steam the subdivision into a fine mist results, in the furnace, in the almost instantaneous vaporization of the oil. The air which is led in with the spray becomes mechanically mixed with it, and with the high temperature in the furnace all conditions are fulfilled and combustion ensues.

**Gas Furnaces.**—With the exception of a few favored localities where natural gas is to be had, the gas used in the furnaces for heating or tempering steel is either coal gas or water gas from the city mains, or producer gas made on the premises.

The heating value of natural gas, at Pittsburgh, is about 900 B.t.u. per cubic foot. Coal gas (illuminating) has a heating value of about 600 B.t.u. per cubic foot. The gross heating value of carburetted water gas enriched by the addition of oil gas will average the same, approximately equivalent to 550 B.t.u. net. Water gas, because of its convenience, moderate cost, and heating power, is now largely used in industrial plants, and its use is constantly extending.



**Flameless Combustion Furnace.**—The underlying principle of this furnace is much the same as that of a Welsbach gas mantle; it consists in burning a mixture of gas and air in intimate contact with a highly refractory granulated material surrounding the muffle to be heated. Common fire-brick begins to soften at a temperature of about 1300° C. (2372° F.), and melts at about 1740° C. (3164° F.).

The accompanying sketch shows a muffle furnace arranged for the application of gas heating by this system. The upper limit of temperature attainable with this system is about 1500° C. (2732° F.). The highest thermal efficiency (95%) is obtained under these conditions, for the mixture of gas and air is then almost in theoretical proportions, and there is no unnecessary surplus of air being raised to this high temperature. The broad advantages of this system of heating are, that a considerably higher temperature and efficiency are obtained than by the ordinary methods of heating by gas, and that the control of the temperature and heating effect is simple and instantaneous.

The thermal efficiency as compared with the ordinary methods of flame heating is shown in results obtained with a muffle furnace in which the muffle was 9¼ inches long by 5½ inches wide by 3¼ inches high, maintained at temperatures between 815 and 1425° C. (1499 to 2597° F.), with coal coal-gas of 540 B.t.u. net. (See table on page 488.)

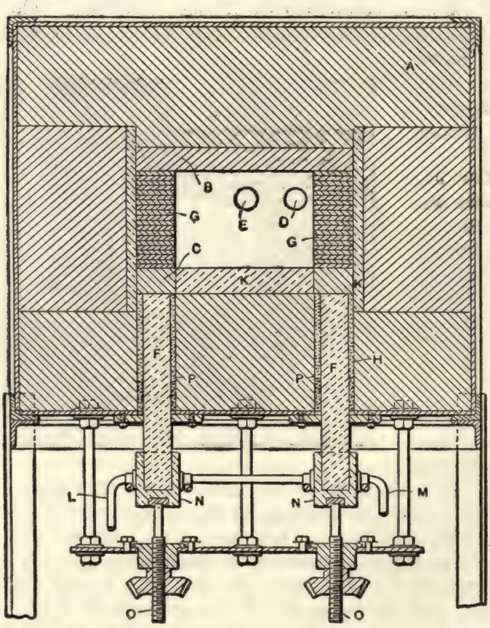
The temperature of the escaping products is 300 to 350° C. (572 to 662° F.) lower than that of the muffle; with a muffle temperature of 1424° C. (2595° F.) there was no appearance of flame at the top of the furnace. The gas consumptions recorded are economical in comparison with those required for ordinary heating by flame contact.

In a similar test with a muffle of the same size heated by flame contact, the gas consumption to maintain the muffle at 1055° C. (1931° F.) (the maximum temperature obtainable) was 105 cubic feet per hour, whereas consumption on the flameless combustion furnace at the same temperature would have been about 43 cubic feet per hour.

| Temperature in Middle of Muffle | | Gas Consumption to Maintain Temp. Constant Cubic Feet per Hour at 15° C. | Temperature of Products | |
|---|---|---|---|---|
| Deg. Cent. | Deg. Fahr. | | Deg. Cent. | Deg. Fahr. |
| 815 | 1,499 | 21.0 | 540 | 1,004 |
| 1,004 | 1,840 | 35.3 | 645 | 1,193 |
| 1,205 | 2,201 | 58.0 | 870 | 1,598 |
| 1,424 | 2,595 | 79.0 | 1,085 | 1,985 |

**Electric Heating Furnace.**—The modern electric furnace, with its perfect heat control, reducing atmosphere, absence of all products of combustion, and thermoelectric pyrometer for measuring the temperature, offers a most attractive method for the heat treatment of tool steel.

Electric heat can be produced by means of the electric arc, as in the arc lamp, or by the resistance of a conductor, as in the incandescent lamp. It is the latter principle utilized by Mr. A. L. Marsh in the electric furnace here described for the heat-treatment of steel. The chamber in this furnace is 18 inches deep (front to back), 12 inches wide and 8 inches high; the relation of the various constructional parts is clearly shown in the illustration, in which: A represents the fire-clay insulation; B, the carbon connector plates; C, the graphite bottom plates; D, the draft hole; E, the pyrometer hole; F, the electrodes; G, the resister plates; H, fire sand; K, cement filling; L, the inlet for the water used for cooling the electrode clamps; M, the outlet for this water; N, the electrode clamps; and O, the pressure regulating screws. The electrodes are surrounded by asbestos at P.




The full length of the side walls and the entire roof of the chamber are formed by the heating elements; the walls are composed of a series of thin carbon plates resting on the top of a heavy block of the same material, and the roof of a thick graphite plate connecting these two columns at the top. One graphite electrode projects up to the middle of each side-wall plate and connects electrically, through water-cooled clamps at the lower end, with the source of energy. The chamber floor is of cement. Outside of the carbon plates there is a lining of the same material. This lining, with a carefully designed backing of heat-resisting material, retains the heat developed within the furnace. A counterweighted door fitted with a peep-hole serves as a quick access to the chamber, while in the rear wall are holes for the insertion of a pyrometer tube and for draft regulation. A rigid enclosing case of steel holds all parts securely.

**Principle of Operation.**—A heavy low-voltage electric current is supplied through the electrodes to the resister plates forming the side walls of the working chamber. Heat is generated here, due to the resistance offered by these plates to the passage of the current. The electrical "resistivity" of the carbon causes each plate to heat exactly as the carbon filament in the incandescent lamp " lights " when the current is turned on. In addition to this action, advantage is taken, in the furnace, of a second form of electrical resistance—that of the contact of one plate with another. This may be readily varied by altering the mechanical pressure on the plate columns by means of the hand-screws. The turning of these changes the resistance of the circuit and hence the resulting temperature produced.

Normal working temperatures are acquired in a little over an hour's time after the switch has been closed. An average of 12½ kilowatt energy consumption will maintain the chamber at approximately 1232° C. (2250° F.); higher temperatures, up to 1371° C. (2500° F.), which is above the requirements of high-speed steels, or lower, as desired, may be obtained by increasing or decreasing the energy supply.

## HEATING BATHS

Crucible furnaces adapted for lead, cyanide of potassium, or barium chloride are in very general use. The furnace fuel is either gas or oil. The flame from the burners is projected, tangentially, into the heating chamber and rotates about the crucible, the products of combustion escaping through an opening in the rear. The temperature is uniform and easily controlled. Baths are in favor for heating and tempering small tools and other articles of steel. The temperature of the bath can be continuously maintained at any degree between the melting and the vaporizing points of the material used. The work being submerged in the bath soon acquires that temperature and can go no higher; the work is also protected from the atmosphere, and oxidation does not take place.

**The Lead Bath.**—Lead melts at 327° C. (621° F.); it is said to vaporize at about 649° C. (1200° F.); its boiling point is given as about 1480° C. (2700° F.). The available work temperatures of the bath for carbon tool steel will range from 332° C. (630° F.) to, say, 870° C. (1600° F.), which can be attained through proper furnace control. A lead bath operating at high temperatures should be provided with a hood to carry off the poisonous vapors arising from the crucible. The temperature of the molten metal should be obtained by pyrometer measurement only. A thick coating of powdered charcoal should be put on top of the molten lead to lessen oxidation, it also assists in maintaining an even temperature. For hardening purposes the lead bath is mostly confined to carbon steel tools, which, if of large size, should be slowly preheated before immersing in the lead bath; a temperature, at least half that of the melted lead in the crucible, will lessen the risk of breakage through unequal expansion. The specific gravity of cast lead is 11.25 or 0.406 pound per cubic inch. The specific gravity of steel is 7.8 or 0.220 pound per cubic inch—nearly one-half lighter than the lead bath. Steel tools must, therefore, be held down in the bath, as if left free they would float. For hardening purposes the lead should be free from sulphur or other impurities which have an injurious effect on the polished surfaces of steel tools.

The sticking of lead to the surface of tools immersed in it is very annoying as it contributes to uneven hardness during the process of quenching. An efficient protective coating which does not interfere with heating or hardening is to apply with a paint brush a thin coating of whiting mixed in denatured alcohol.

**Cyanide of Potassium Bath.**—The specific gravity of KCN is 1.52; its melting point is that of a dull red heat, about 540° C. (1000° F.). Furnaces for melting cyanide of potassium are similar to those for melting lead. The melting pot may be cast iron or pressed steel, in either case it is suspended in the heating chamber by its flanged top. The furnace should be provided with a hood to carry off the poisonous fumes from the melting pot and pass them into the chimney.

Cyanide hardening is employed by bank-note engravers for hardening transfer rolls and engraved plates, also by manufacturers of cutters, dies, springs, and other steel work requiring a hard surface without great depth of case

When the molten cyanide is raised to the proper temperature the parts to be treated are entirely immersed by suspending on a wire, or a number of small parts may be treated at once by placing them in an open mesh-wire basket which is suspended in the bath. The extreme depth of hardening is obtained in about 20 minutes, a longer treatment in the bath will not add to the depth of hardness already obtained.

**Barium Chloride Bath.**—Barium chloride crystallizes in transparent, colorless, rhombic tables, having a specific gravity 2.66 to 3.05. The crystals have an unpleasant, bitter, sharply saline taste, exciting nausea, and are very poisonous. The fusing temperature is 890° C. (1635° F.).

The furnace should preferably be gas fired, the flame encircling the crucible as already described for melting lead. The crucible should be of graphite and rest upon fire-bricks so spaced that the hot gases shall pass under as well as around it. To start the bath: fill the crucible with barium chloride including about 2% of sodium carbonate (soda ash), heat the crucible until these two substances are melted together, about 1200° C. (2192° F.). The furnace is then ready for use.

High speed steel requires a higher temperature for hardening than does carbon steel; the barium chloride bath will range from 1000 to 1200° C. (1832 to 2192° F.). It is expected of the man operating the furnace that the composition of the steel be known as also the best temperature for its treatment. A pyrometer should be used in all temperature measurements.

When the bath has been heated to the temperature suited to the composition of the steel the tool, if a small one, is then placed in the bath and kept there until it has acquired the same temperature. Large tools should be preheated to a low red in a muffle or other suitable furnace to prevent chilling the bath. The time required will vary according to the size and form of the tools. Mr. Becker states that in the case of small and regularly shaped tools it will range from a few seconds to a minute; those of ½-inch section or less should be ready in less than a minute.

When a tool not preheated is plunged into the bath a coating of barium chloride immediately solidifies upon its surface; this coating protects the tool until its temperature rises to that of the bath when it melts off. This coating is useful in preventing blisters on the surface of the steel, and in preventing the melting down of sharp corners or points of a tool which sometimes occurs when a cold tool is put into a very hot oven furnace. This coating also prevents oxidation of the tool by protecting it from the atmosphere when removing it from the crucible to the cooling bath. Since the temperature of the bath is no higher than that to which the tool is to be raised, the latter is not damaged by remaining in the bath for some time longer than would be required merely to heat it through uniformly; but tools should not be left in the bath longer than is absolutely necessary.

Sodium carbonate (soda ash), when the quantity exceeds about 2%, affects the liquid barium chloride by lowering its capacity for heat at the higher temperatures; it also makes regulation of temperature more difficult. Mr. Becker says the boiling point of the bath seems to be lowered approximately in proportion to the excess of soda ash; and since it is very difficult, if indeed it is at all possible, to raise the temperature above the boiling point, the tools cannot be heated high enough to be properly hardened. The soda ash gradually becomes exhausted and requires renewal; in renewing, the soda ash should be intimately mixed with several times its own bulk of barium chloride before being added to the bath. It is dangerous to throw soda ash crystals into the melted barium chloride.

**Disadvantages of Barium Chloride Bath.**—In a leading article published in *Machinery*, April, 1911, it is stated that tools heated for hardening in a crucible containing barium chloride have a soft scale or film of soft metal, perhaps about 0.003 to 0.006 inch deep, all over the surface of the tool. Careful experiments have been made to ascertain as nearly as possible the conditions which contribute to produce such unsatisfactory results. Comparison has been made between tools made from the same material of which some were hardened by heating in barium chloride and some in an oven furnace. The results of these experiments are recorded below.

To make the tests as simple and conclusive as possible, pieces of high-speed steel, ½ inch thick, were cut off from one bar of steel. These were hardened, heating some in

a common oven furnace, and others in barium chloride. The pieces were heated from the room temperature to the hardening temperature without preheating. The barium chloride was chemically pure. The temperatures were measured by a pyrometer, and the hardness tests were by scleroscope. After heating, the pieces were immersed in a cooling bath of cottonseed oil at 38° C. (100° F.). The temper was drawn in an oil tempering bath at 260° C. (500° F.).

When the pieces were heated in the oven furnace, the operator used his own judgment as to when to remove each piece from the furnace and plunge it into the hardening bath; the time required for the piece to acquire proper hardening heat was recorded, and given in the table.

After the pieces had been hardened and tempered as described, an amount equal to 0.005 inch was ground off from one side of each piece, which we call the face, and an amount of 0.002 inch was ground off the other side, the back. The surfaces presented to the scleroscope were thus perfectly smooth and uniform. The results are given in the table, the values being the average of the several readings.

The pieces heated in barium chloride at 1149 to 1316° C. (2100 to 2400° F.) were found to be pitted, and small beads of a metallic structure adhered to the pieces. Similar small pieces were found in the bottom of the crucible after all the test pieces had been hardened. This residue was chemically analyzed and was found to consist principally of ferro-tungsten.

Heating in an oven furnace gave results almost uniformly better according to the heat at which the pieces were hardened. The higher the heat, the higher the scleroscopic test number. When the pieces were heated in barium chloride, a result entirely different was obtained, and at temperatures of 1149 to 1316° C. (2100 to 2400° F.), the results were, in general, very unsatisfactory. Pieces that were 18 minutes in the heating bath were almost uniformly softer, the higher the hardening heat, indicating that some soft scale remained after removal of 0.005 inch by grinding. In almost every case the back, where 0.002 inch was removed, is softer than the face of the test piece, due to the fact that the soft scale is deeper than 0.002 inch; whereas the face, where 0.005 inch had been ground off, shows greater hardness. Tests were next made to ascertain the influence on the cutting qualities of tools hardened either by heating in barium chloride or in an oven furnace. These tests proved conclusively that tools heated in the barium chloride bath did not stand as high a cutting speed as did those hardened after heating in an oven furnace.

## HARDENING AND TEMPERING HIGH-SPEED STEEL TOOLS

A method of preparing such tools is thus given by J. M. Gledhill: After forging the tools, and when quite cold, grind to shape on a dry stone or dry emery wheel; the tool then requires heating to a white heat, just short of melting, and afterward completely cooling in the air blast. This method of first roughly grinding to shape also lends itself to cooling the tools in oil, which is specially efficient where the retention of a sharp edge is a desideratum, as in finishing tools, capstan and automatic lathe tools, brass-workers' tools, etc. In hardening where oil cooling is used, the tools should be first raised to a white heat, but without melting, and then cooled down either by air blast or in the open to a bright red heat, say, 927° C. (1700° F.), when they should be instantly plunged into a bath of rape or whale oil, or a mixture of both.

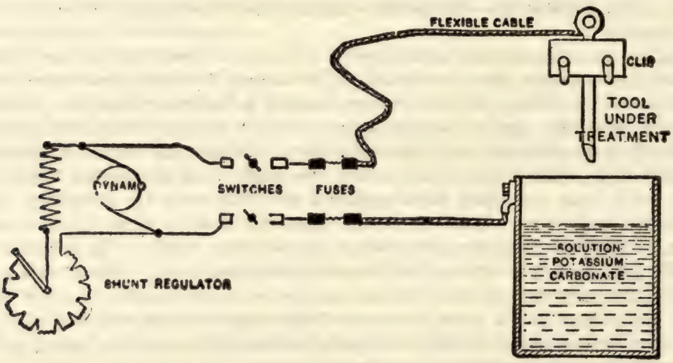
Specially formed tools of high-speed steel, such as milling and gear cutters, twist drills, taps, screwing dies, reamers, and other tools that do not permit of being ground to shape after hardening, and where any melting or fusing of the cutting edges must be prevented, the method of hardening is as follows: A specially arranged muffle furnace heated either by gas or oil is employed, and consists of two chambers lined with fireclay, the gas and air entering through a series of burners at the back of the furnace, and under such control that a temperature up to 1204° C. (2200° F.) may be steadily maintained in the lower chamber, while the upper chamber is kept at a much lower temperature. Before placing the cutters in the furnace it is advisable to fill up the hole and keyways with common fire-clays to protect them.

The mode of procedure is as follows: The cutters are first placed upon the top

of the furnace until they are warmed through, after which they are placed in the upper chamber and thoroughly and uniformly heated to a temperature of about 816° C. (1500° F.), or, say, a medium red heat, when they are transferred into the lower chamber and allowed to remain therein until the cutter attains the same heat as the furnace itself, viz., about 1204° C. (2200° F.), and the cutting edges become a bright yellow heat, having an appearance of a glazed or greasy surface. The cutter should then be withdrawn while the edges are sharp and uninjured, and revolved before an air blast until the red heat has passed away, and then while the cutter is still warm—that is, just permitting of its being handled—it should be plunged into a bath of tallow at about 93.3° C. (200° F.) and the temperature of the tallow bath then raised to about 271° C. (520° F.), on the attainment of which the cutter should be immediately withdrawn and plunged in cold oil.

**Electric Hardening.**—One method of heating and hardening the point of a high-speed steel tool and the arrangement of apparatus are shown in the accompanying sketch.

It consists of a cast-iron tank, of suitable dimensions, containing a strong solution of potassium carbonate $K_2CO_3$ together with a dynamo, the positive cable from which




is connected to the metal clip holding the tool to be heated, while the negative cable is connected direct on the tank. The tool to be hardened is held in a suitable clip to insure good contact. To harden the tool: The current is first switched on, and then the tool is gently lowered into the solution to such a depth as is required to harden it. The act of dipping the tool into the alkaline solution completes the electric circuit and at once sets up intense heat on the immersed part. When it is seen that the tool is sufficiently heated the current is instantly switched off, and the solution then serves to rapidly chill and harden the point of the tool, so that no air blast is necessary.

**Colors of Heated Steel.**—The following table by White and Taylor gives results of extended experiments upon colors of heated steel corresponding to different degrees of temperatures. Pouillet constructed a table in 1836, which has been published in various text books; other tables have appeared from time to time, but these differ so widely among themselves that they lack authoritative standing, a condition due to defective apparatus used for determining the higher temperatures, and to the fact that observers have a different eye for color, which leads to quite a range of temperatures covering the same color. White and Taylor found that the quality or intensity of light in which color heats are observed—that is, a bright sunny day, or cloudy day, or the time of day, such as morning, afternoon, or evening, with their varying light—influences to a greater or less degree the determination of temperatures by the eye.

After many tests with the Le Chatelier pyrometer, and different skilled observers working in all kinds of intensity of light, they adopted the following nomenclature of color scale with the corresponding determined values in degrees Fahr. as best suited to the ordinary conditions met with in the majority of smith's shops:

| | Fahr. Deg. | Cent. Deg. |
|---|---|---|
| Dark blood red, black red | 990 | 532 |
| Dark red, blood red, low red | 1,050 | 566 |
| Dark cherry red | 1,175 | 635 |
| Medium cherry red | 1,250 | 677 |
| Cherry, full red | 1,375 | 746 |
| Light cherry, bright cherry, light red (heat at which scale forms) | 1,550 | 843 |
| Salmon, orange, free scaling heat | 1,650 | 899 |
| Light salmon, light orange | 1,725 | 935 |
| Yellow | 1,825 | 996 |
| Light yellow | 1,975 | 1,079 |
| White | 2,200 | 1,204 |

With the advancing knowledge of the heat treatment of steel, the foregoing will prove of value to those engaged in the handling of steel at various temperatures. The importance of knowing with close approximation the temperatures used in the treatment of steel cannot be overestimated, as it holds out the surest promise of success in obtaining desired results.

This demand for more accurate temperatures must eventually lead to the use of accurate pyrometric instruments; but at present the only available instruments do not lend themselves readily to ordinary uses, and the eye of the operator must be largely depended upon; therefore, the training of the eye, by observing accurately determined temperatures, will prove of much material assistance in the regulation of temperatures which cannot be otherwise controlled.

## QUENCHING BATHS

Carbon tool steels are usually quenched in water, the most efficient of all quenching fluids, because of its high specific heat and great capacity for taking up heat at any temperature between freezing and boiling points. The bath should be large and supplied with running water where large pieces are to be hardened. In water quenching, a thin film of vapor forms on the surface of the tool, checking the absorption of heat from the tool in still water; a stream of boiling water often hardens more than does still, but cold water.

The temperature at which hardening occurs in carbon tool steel seems to be that at which the metal begins to exhibit color, a low, barely visible red heat as seen in the dark. Any treatment which by quickly reducing this temperature, as in water quenching, will harden the steel.

The change which occurs in hardening carbon steel is a physical alteration of structure at some point between 427 and 538° C. ( 800 and 1000° F.), and is the more complete as the reduction of temperature of the metal is the more rapid. Cooling should, therefore, be moderately rapid, complete, and perfectly regular.

Brine produces the sharpest results, but is severe, and has a greater tendency to warp the parts. It produces a higher elastic limit than either water or oil. Water is intermediate between brine and oil in its tendency to warp the parts, nor can so high an elastic limit be obtained with it as with brine.

Fish oil, cottonseed, lard, tallow, and paraffine oils are the mildest of the quenching mediums, and are extensively used. It does not make much difference which oil is used, but the quenching bath must be sufficiently large that the heat be absorbed quickly from the tool. Tools cooled in oil are, in general, harder than those cooled by means of an air blast.

Air quenching is rendered less objectionable as regards oxidation when the high-speed tool has been heated in a barium chloride bath because a thin film of the chloride completely covers it and effectually prevents metallic contact with the air. When tools are air quenched a force blast is necessary in order to carry off the heat quickly.

Tools with delicate edges will require tempering after air quenching, which is usually accomplished in an oil bath. After the removal of the barium chloride film the tool will be found to be of its original size, and much the same appearance as before heating.

Quenching and hardening high-speed steel: The methods employed are by no means uniform, largely depending upon the composition of the steel.

Mushet's self-hardening steel (1868), also known as air-hardening steel, derived its name from the fact that when heated to an orange color, say, 910° C. (1670° F.) and allowed to cool slowly in the air it becomes exceedingly hard. The usual composition of this steel was 2 to 3% manganese; 4 to 6% tungsten, and carbon high. The distinctive, persistent hardness of manganese steel indicates that it is manganese that gives this steel its so-called self-hardening property. Air-hardening steel, as a rule, is not tough, that is to say, if it is made tough it will not be very hard. The edge of the tool will flow, and when it is so hard that it will not flow then it is so brittle that it will crumble easily.

Heating and hardening the later high-speed tool steels, a composition such as for lathe and planer use, it is necessary to almost melt the point of the tool, quench it in a strong air blast, and then grind to shape. Such tools are made from annealed bars, differing in this respect from the earlier air-hardening steels. The finished tools are heated in a lead bath of 982 to 1093° C. (1800 to 2000° F.), and quenched quickly in ordinary tempering oil which must be kept cool by a coil containing circulating cold water; they are then tempered in a bath of heavy oil heated to about 232° C. (450° F.), the tools should come out of the bath bright and clean.

**Double Hardening.**—This consists of a preliminary hardening, followed by annealing at a lower or higher temperature, with a view to eliminating strains, and again hardening. This double hardening does not affect the strength and extensibility of the metal, but it eliminates the yield-point, which is very important in the case of springs, etc. A spring, hardened in the ordinary way, is completely pressed together when the yield-point is reached, but with a double hardened spring this is different. As soon as the limit of elasticity is exceeded, it suffers a slight deformation, but the limit of elasticity immediately increases again, and the deformation ceases. Double hardening also decreases brittleness.

## ANNEALING

If carbon tool steel is annealed at a temperature where martensite is formed it will contain a portion of the hardening element. By a judicious application of heat it is possible to obtain almost any desired combination of ferrite, pearlite, and martensite. Tools when properly handled should be heated first to the proper temperature or critical point, and then quenched. Heating above this point tends to produce decarbonization. If a tool is heated too hot and then allowed to cool slowly before quenching it will, according to Sullivan, have a grain structure developed by the higher temperature which is not corrected by allowing the tool to cool before quenching. Tools should not be allowed to soak too long even at the proper temperature, as this tends to produce decarbonization on the surface.

**Annealing Mild Steel.**—The following is an abstract from a communication by Professor Heyn to the Iron and Steel Institute, 1902:

1. When low carbon mild steel is annealed at 1000° C. there occurs an increase in the degree of brittleness if the annealing period is sufficiently long. By a judicious adjustment of the annealing temperature and period, it is possible to produce any desired degree of variation in the brittleness of mild steel within definite limits.

2. Prolonged annealing, say, uninterrupted for fourteen days, at temperatures between 700° and 890°, produces no increase in the brittleness. In such cases where the brittleness of the metal in its initial state is not yet at the lowest degree possible, by this treatment the lowest degree of brittleness will be attained.

3. Between 1100° and 900° there exists a temperature limit, above which, if annealing is carried on for a longer period and at an increasing temperature, the degree of brittleness increases. Below these limits, however, this is not the case.

4. Overheating not only occurs at a most extreme white heat, but manifests itself already at considerably lower temperatures, which must, however, exceed the tem-

perature limit referred to in No. 3, the degree being more marked the longer the annealing period.

5. By suitable annealing, the brittleness of overheated mild steel can be eliminated. If annealing is carried on above 900° C., the short period of about half an hour is sufficient. Below 800° an annealing of even five hours is not sufficient to eliminate the brittleness in overheated mild steel.

6. If mild steel, which has been annealed for a longer period, at a high enough temperature, so that after undisturbed cooling it would show extreme brittleness, is rolled or forged during cooling at a bright red heat, it will exhibit no brittleness when cold.

7. The fracture of overheated mild steel generally shows a coarse grain, although it is not necessarily always the case.

8. The single crystal grains of which the structure of the iron is built up, and which can be detected under the microscope by suitable etching, are often of considerable dimensions when in the state of overheating. Nevertheless, this is not to be considered as proof positive that overheating has taken place, since the period of cooling also exercises a great influence on the size of the ferrite grains. Rapid cooling, from the temperature causing overheating, produces fine ferrite grains, without appreciably reducing the brittleness.

## COMPOSITION AND HEAT TREATMENT OF CARBON STEEL OTHER THAN TOOL STEELS

The 30, 80 and 95% carbon steels given below are abstracted from second report made by the Iron and Steel Division of the Society of Automobile Engineers' Standards Committee, 1911.

While the steels and methods of heat treating them have been prepared more especially for automobile construction, they also can be used in a large number of cases for manufacturing other products.

### Carbon Steel—0.45%

**Composition.**—Carbon, 0.40 to 0.50% (0.45% desired); manganese, 0.50 to 0.80% (0.65% desired); silicon, not over 0.20%; phosphorus, not over 0.04%; sulphur, not over 0.04%.

**Characteristics and Uses.**—The natural sources of supply of this steel are basic or acid open hearth, and crucible or electric furnace, the most common being the basic open hearth. This steel possesses greater strength for structural purposes than 0.30 carbon steel. Its uses, however, are more limited and are confined in a general way to such parts as demand a high degree of strength and a relatively low degree of toughness. With proper heat treatment the fatigue resisting qualities are very high. The principal uses for this steel are: Crankshafts, driving-shafts, propeller-shafts and transmission gears. It is not hard enough, however, without case-hardening, and is not tough enough with case-hardening to make safe transmission gears, and should not be used for case-hardened parts, except in an emergency. In the annealed condition this steel should have an elastic limit of about 50,000 pounds per square inch, and after heat treating the elastic limit may be nearly doubled.

**Heat Treatment.**—After forging or machining: 1. Heat to 1550° F. 2. Quench. 3. Anneal by heating to 1450° F. 4. Cool slowly in furnace, in lime or soft coal. 5. Reheat, 1400 to 1500° F. 6. Quench. 7. Heat, 800 to 1000° F. and cool slowly.

### Carbon Steel—0.80%

**Composition.**—Carbon, 0.75 to 0.90% (0.80% desired); manganese, 0.25 to 0.50% (0.35% desired); silicon, 0.10 to 0.30%; phosphorus, not over 0.035%; sulphur, not over 0.035%.

**Characteristics and Uses.**—This steel is used principally for springs, and, generally speaking, for springs of light section. Its sources of supply may be the open hearth, crucible, or elastic furnace.

**Heat Treatment.**—It must be understood that the higher the drawing temperature, the lower will be the elastic limit of the material. On the other hand, if the material be drawn to too low a temperature it will be brittle. The hardening and drawing of springs, that is, the heat treatment of them, is as a rule in the hands of the spring-maker, but for small coil springs, the following treatment is recommended: 1. Coil. 2. Heat, 1400 to 1500° F. 3. Quench in oil. 4. Reheat, 400 to 500 or 600° F. in accordance with the degree desired, and cool slowly.

Carbon Steel—0.95%

**Composition.**—Carbon, 0.90 to 1.05% (0.95% desired); manganese, 0.25 to 0.50% (0.35% desired); silicon, 0.10 to 0.30%; phosphorus, not over 0.035%; sulphur, not over 0.035%.

**Characteristics and Uses.**—This steel is obtained from the same sources as 0.80 carbon steel and is used principally for springs.

**Heat Treatment.**—Substantially the same remarks apply to this steel as to 0.80 carbon steel. The heat treatment may be reduced slightly because of the increased carbon content, and possibly the drawing temperature will be different.

## HARDENING OF CARBON AND LOW-TUNGSTEN STEELS

A research on the hardening of carbon and low-tungsten tool steels has been conducted by Mr. Shipley N. Brayshaw, of Manchester, England, and the results of his investigations were presented to the Institution of Mechanical Engineers in 1910.

The paper deals exclusively with the results obtained from two kinds of carbon tool steel that, except for minute variations, differed only in the fact that one of them contained about 0.5% of tungsten. The steel contained on an average of 1.16% carbon, 0.15% silicon, 0.36% manganese, 0.018% sulphur, and 0.013% phosphorus. The whole work of investigation was devoted to questions directly connected with machine-shop hardening.

**Hardening Temperatures.**—The hardening point of both low-tungsten and carbon steel may be located with great accuracy, and the complete change from soft to hard is accomplished within a range of about 10° F. or less. After the temperature has been raised more than from 35 to 55° F. above the hardening point, the hardness of the steel is lessened by further increases in the temperature, provided the heating is sufficiently prolonged for the steel to acquire thoroughly the condition pertaining to the temperature.

**Change Point.**—There is a change point at about 879° C. (1615° F.) in low-tungsten steel and at a somewhat higher temperature in carbon steel. One of the several indications of this change point is the shortening of bars hardened in water at temperatures below that point, whereas the bar lengthens if this temperature is exceeded at the time of quenching. Practically the same results are obtained by heating low-tungsten bars to any temperature from 760 to 940° C. (1400 to 1725° F.) and quenching in oil as by quenching in water.

**Length of Time of Heating.**—Prolonged soaking up to 120 minutes at temperatures at which the hardening change is half accomplished in 30 minutes does not suffice to complete the change. Prolonged soaking for hardening at a temperature of 760° C. (1400° F.) has a slightly injurious effect on the steel, but does not materially influence the hardness. At a temperature of about 810° C. (1490° F.) a great degree of hardness is attained by quick heating, but the hardness is impaired with 30 minutes' soaking. Prolonged soaking for hardening at a temperature of about 879° C. (1615° F.) has a seriously injurious effect upon the steel. A specially great degree of hardness may be obtained by means of soaking at a high temperature, such as 879° C. (1615° F.) for a very short time, but even as long a time as 7½ minutes is long enough to seriously impair the hardness.

The temperature of brine for quenching is of considerable importance. Both low-tungsten and carbon steel bars quenched at 5° C. (41° F.) were decidedly harder than bars quenched at 24° C. (75° F.), and quenching at 51° C. (124° F.) rendered the bars much softer.

**Previous Annealing.**—The method of previous annealing affects the hardness of steel considerably. The elastic limit of low-tungsten bars hardened at either 760° C. (1400° F.) or 860° C. (1580° F.) varies according to the annealing they have undergone. The elastic limit is higher after annealing at about 799° C. (1470° F.) for 30 minutes, or 699° C. (1290° F.) for 120 minutes, but it is seriously impaired by annealing at 799° C. (1470° F.) for 120 minutes. If low-tungsten steel is annealed at 941° C. (1725° F.) and hardened at 760° C. (1400° F.) the elastic limit is inferior, and the adverse effect of the previous annealing is much more pronounced if the hardness is done at 860° C. (1580° F.). The elastic limit of carbon steel annealed at any temperature between 699 and 941° C. (1290 and 1725° F.) and hardened at either 760° or 860° C. (1400 or 1580° F.) does not vary by nearly such great amounts as the elastic limit of the low-tungsten bars, and the highest annealing temperature given above is not injurious so far as the elastic limit is concerned.

The hardness of low-tungsten bars hardened at 760° C. (1400° F.) decreases from a high scleroscope figure to a low one as the temperature of annealing increases from 699 to 941° C. (1290 to 1725° F.). The hardness is increased by prolonging the annealing at the lower temperature. The hardness of low-tungsten steel hardened at 860° C. (1580° F.) is fairly constant at a moderately high scleroscope figure, whatever the temperature of annealing.

**Heating in Two Furnaces.**—Experiments show that low-tungsten and carbon steel bars heated for half an hour to temperatures between 841 and 899° C. (1545 and 1650° F.) are not much affected so far as their elastic limit and maximum strength are concerned by a further immediate soaking for half an hour at 760° C. (1400° F.). If, however, the temperature in first furnace is 941° C. (1725° F.), the low-tungsten steel is much improved by a further soaking at 760° C. (1400° F.), but the carbon steel is much injured by the same treatment. Bars of low-tungsten steel heated for 30 minutes at 880° C. (1616° F.), and then soaked at 722° C. (1332° F.) for a further 30 minutes, give a high elastic limit and maximum strength, and are harder than if the second soaking were at a temperature of 760° C. (1400° F.). The carbon steel, again, is but little affected by these variations in the second furnace.

**Change of Length in Hardening.**—Both low-tungsten and carbon steel is much affected by the above variations in the temperature of the second furnace. Good results as regards elastic limit and maximum strength, and also as regards hardness, are obtained by very short soaking, first at a high temperature, say, 879° C. (1615° F.), and then at a low one, the results being best when the second temperature is near to or a little below the hardening point. If the furnace be at a sufficiently high temperature it is easy either by variations of the temperatures of the two furnaces, or by variations in the time of soaking, to arrive at a treatment of the steel, both low-tungsten and carbon, whereby they neither lengthen nor shorten. Under the same treatment carbon steel has a greater tendency to shorten than low-tungsten steel.

**Miscellaneous Results.**—Other experiments showed that low-tungsten steel heated at 860° C. (1580° F.) for 15 minutes and quenched in oil has a higher elastic limit and is harder than carbon steel similarly treated. As regards annealing, it was found that bars annealed at a temperature of 799° C. (1470° F.) or below became slightly shorter by the annealing process, and its action was more pronounced in the case of carbon steel than tungsten steel. Annealing at a temperature of 899° C. (1650° F.) causes both low-tungsten and carbon steel to lengthen.

It was found that recalescence of low-tungsten steel takes place gradually at a temperature of 731° C. (1348° F.) and more readily at 725° C. (1337° F.) and, further, that the recalescence at either of the above temperatures is very much retarded if the steel is cooled from a maximum heat of 890° C. (1634° F.).

Regarding hardening cracks, it is shown that both for low-tungsten and carbon steel, such treatment as produced the highest elastic limit accompanied by the greatest hardness is frequently the most risky. The risk of hardening cracks is reduced if the steel is heated for a sufficient length of time to a temperature of 899° C. (1650° F.) or a little above. Low-tungsten steel is more liable to crack in hardening than is carbon steel.

**Effect of Tempering.**—Tempering experiments showed that little effect was pro-

duced by the tempering of carbon steel to 149° C. (300° F.) for 30 minutes. Tempering the same steel to 249° C. (480° F.) for 15 minutes, however, caused it to soften considerably and to shorten in length. For low-tungsten steel the elastic limit was increased considerably by tempering up to a temperature of 249° C. (480° F.). The maximum strength of the same steel coincides with the elastic limit for bars either untempered or tempered at 149° C. (300° F.) for 15 minutes, but it then rises rapidly with further tempering. The hardness, as measured by the scleroscope, was considerably reduced by tempering at 149° C. (300° F.) and still more at 199° C. (390° F.), but was not so much affected by further tempering at 249° C. (480° F.). The length of the low-tungsten bars was reduced by tempering up to a temperature of 249° C (480° F.), the higher the temperature, the greater was the reduction in length.

**Tensile Strength.**—The following conclusions refer to low-tungsten steel, but there is no reason to doubt that they are also applicable to carbon steel. A very good bar was produced by quenching from a temperature fully 42° C. (108° F.) above the hardening temperature. A heat of only 5 minutes' duration produced a harder bar than a heat of 25 minutes, the maximum temperature in both cases being 799° C. (1470° F.), or a little above; but the bar heated for a shorter time gave a much lower elastic limit. The following has reference to both tungsten and carbon steels: Tempering up to a temperature of 299° C. (570° F.) gradually increases the maximum strength, the elastic limit, and reduces for a given stress the extension under load and the permanent extension.

## COMPOSITION AND HEAT TREATMENT OF CARBON AND ALLOY STEELS

Soc. Auto. Engrs., Standards Committee, 1911)

### Nickel Steel—0.30% Carbon, $3\frac{1}{2}$% Nickel

**Composition.**—Carbon, 0.25 to 0.35% (0.30% desired); manganese, 0.50 to 0.80% (0.65% desired); silicon, not over 0.20%; phosphorus, not over 0.04%; sulphur, not over 0.04%; nickel, 3.25 to 3.75% (3.50% desired).

**Characteristics and Uses.**—This steel is primarily intended for heat treating, and is used for structural parts where much strength and toughness are desired: such parts as axles, spindles, crankshafts, driving-shafts, and transmission-shafts. The elastic limit in the annealed condition is about 55,000 pounds per square inch. By heat treatment this may be increased to 160,000 pounds per square inch, the ductility at this point being satisfactory, and a reduction of area of at least 45% being obtainable. The wide variation in the elastic limit is obtained by the use of different quenching mediums—brine and oil—and a difference in the drawing temperatures.

**Heat Treatment.**—After forging and machining: 1. Heat, 1450 to 1500° F. 2. Quench. 3. Heat, 600 to 1200° F. and cool slowly.

A higher refinement of this treatment is: After forging and machining: 1. Heat, 1450 to 1500° F. 2. Quench. 3. Reheat, 1350 to 1400° F. 4. Quench. 5. Heat, 600 to 1200° F. and cool slowly.

By the proper regulation of the quench and drawing temperatures, a wide range of physical characteristics may be obtained. The thickness of the mass treated, the volume and temperature of the quenching medium, and other details peculiar to most hardening plants must be recognized in order to get intelligent and desirable results. This material may be case-hardened, but it contains a rather high carbon content for this purpose. The lower ranges of carbon—0.25%—are satisfactory, but the upper ranges—in the neighborhood of 0.35%, approach the danger point, and steel of this carbon content must be correspondingly carefully hardened.

### Chrome-Nickel Steel—0.30% Carbon

**Composition.**—Carbon, 0.25 to 0.35% (0.30% desired); manganese, 0.30 to 0.50% (0.40% desired); silicon, 0.10 to 0.30%; phosphorus, not over 0.04%; sulphur, not over 0.04%; nickel, 3.25 to 3.75% (3.50% desired); chromium, 1.25 to 1.75% (1.50% desired).

**Characteristics and Uses.**—This grade of chrome-nickel steel is intended largely for structural parts of the most important character; parts requiring this high grade of steel must be heat treated, otherwise there is no gain commensurate with the increased cost of the steel. It is suitable for crankshafts, axles, spindles, driving-shafts, transmission-shafts, and, in fact, the most important structural parts of an automobile. The elastic limit in the annealed condition is of no importance, as this steel should not be used in the annealed state. The elastic limit after heat treating may be as high as 175,000 pounds per square inch, with a generous reduction of area and elongation.

**Heat Treatment.**—After forging and machining: 1. Heat, 1450 to 1500° F. 2. Quench. 3. Reheat to a temperature between 500 and 1250° F. and cool slowly.

A higher refinement of this treatment is, after forging: 1. Heat, 1450 to 1500° F. 2. Quench, 3. Reheat to 1400° F. 4. Quench. 5. Reheat to a temperature between 500 and 1250° F. and cool slowly.

The temperatures when treating and annealing should be controlled by a pyrometer.

The lower the temperature at which the proper response to treatment is obtained, the better will be the results. At the same time, if a sufficient temperature is not used, there will be an incomplete or unsatisfactory response. This steel is not intended for case-hardening, but may be so treated in an emergency. If case-hardening is attempted the highest degree of care must be exercised.

## Chrome-Vanadium Steel—0.30% Carbon

**Composition.**—Carbon, 0.25 to 0.35% (0.30% desired); manganese, 0.40 to 0.70% (0.50% desired); silicon, 0.10 to 0.30%; phosphorus, not over 0.04%; sulphur, not over 0.04%; chromium, 0.80 to 1.10% (0.90% desired); vanadium, not less than 0.10 (0.18% desired).

**Characteristics and Uses.**—This steel is used for structural purposes, and for crankshafts, driving-shafts, axles, etc. The physical characteristics in the annealed condition are unimportant, as the steel should not be used in that condition—not that it is unsafe, but because there will be no gain commensurate with the increased cost of the material.

**Heat Treatment.**—After forging and machining: 1. Heat, 1600 to 1700° F. 2. Quench. 3. Reheat to a temperature between 500 and 1300° F. and cool slowly.

The elastic limit after heat treatment may be from 60,000 to 150,000 pounds per square inch, with good toughness as represented by the reduction of area and elongation. This steel may be case-hardened, but if so treated it must be handled with care on account of the relatively high carbon content.

## Chrome-Vanadium Steel—0.45% Carbon

**Composition.**—Carbon, 0.40 to 0.50% (0.45% desired); manganese, 0.60 to 0.90% (0.75% desired); silicon, 0.10 to 0.30%; phosphorus, not over 0.035%; sulphur, not over 0.035%; chromium, 1.00 to 1.30% (1.20% desired); vanadium, not less than 0.10% (0.18% desired).

**Characteristics and Uses.**—This steel contains sufficient carbon in combination with vanadium to harden when quenched at a proper temperature. The elastic limit after suitable treatment may be carried as high as 200,000 pounds per square inch, with a reduction of area great enough to indicate good toughness. This steel may be used for structural parts where exceedingly great strength is required.

**Heat Treatment.**—The information given relative to the heat treatment of 0.30% carbon, chrome-vanadium steel, also applies to this steel. The drawing temperature must be considerably modified to produce proper stiffness. For gears this steel must be annealed after forging. The heat treatment is as follows: 1. Heat to 1600° F. 2. Quench. 3. Reheat to 1450° F. 4. Cool slowly. 5. Reheat, 1600 to 1650° F. 6. Quench. 7. Reheat, 250 to 550° F. and cool slowly.

This last drawing operation (7) must be modified to obtain any desired hardness.

## CASE-HARDENING

This is a process by which to carburize and harden the surface of wrought iron or mild steel by packing the finished articles in an air-tight iron box in contact with some substance rich in carbon, commonly charcoal, bone, or charred animal matter; luting the box cover with fire clay to exclude the air; subjecting the box to a high temperature for several hours and then chilling its contents. The effect is to convert the surface of each article in the box in contact with the carburizing material into a hardening steel. This casing of steel is of varying degrees of thickness, from a mere skin for small parts to ⅛ inch, depending upon the shape and thickness of the part, and upon the furnace temperature—usually about 815° C. (1500° F.)—and upon the length of time the article is subjected to this heat; in any case the time is only such as to case the articles with steel to the desired thickness, which is then hardened by quenching, leaving the inside of the article soft and tough.

**Metals to be Case-Hardened.**—Wrought iron contains but little carbon, seldom more than 0.20%, and from that down to a mere trace the operation of case-hardening is analogous to that of cementation, the difference being that case-hardening is merely a surface conversion of wrought iron into hardening steel, while in cementation the carbon becomes so incorporated with the wrought iron as to completely alter its composition, structure, and properties. The manner in which carbon is thus passed into the iron is not exactly known, probably in the form of gaseous compounds of carbon deposited at the surface of the wrought iron, the combined carbon being then transmitted to the interior by the iron itself.

As the case-hardening process does not eliminate any of the impurities ordinarily found in wrought iron, such as sulphur, phosphorus, etc., an iron should be selected as free as possible from these impurities.

**Mild Steel.**—The carbon content in ordinary carbon steel for case-hardening should be from 0.10 to 0.15%, and in no case should it exceed 0.20%. In alloy steels the carbon content may be as high as 0.30%. The manganese content should not exceed 0.40% if a single quenching only is employed, but can be somewhat higher if two quenchings are used. Silicon increases the brittleness in all cases, and should not exceed 0.30%. Tungsten and molybdenum both increase the brittleness of the core. Nickel seems to retard the process somewhat, and the hardness of the case is somewhat lower than that obtainable in ordinary carbon steels. Steels with from 1.0 to 1.2% chromium are sometimes used when an especially hard case is required. This element aids crystallization of the core, and double quenching is absolutely necessary. Chrome-nickel steels with a low chromium content require about the same heat treatment as pure nickel steels.

**Nickel Steel.**—In the treatment of nickel steel the first quenching for refining the core is not always necessary, although it noticeably increases the tenacity of the core. With a 2% nickel steel the following temperatures are recommended by Guillet. The first quenching should be from a temperature of 1000° C. (1830° F.). The second heating should be to 749° C. (1380° F.), after which the quenching should take place after the objects have cooled off to about 700° C. (1292° F.). A single quenching from 700° C. (1292° F.) gives the greatest hardness in the case but not the greatest tenacity in the core. Quenching from 750° C. (1382° F.) gives a somewhat higher tenacity but a slightly lower hardness in the case. A 6% nickel steel should be quenched in the first instance from 850° C. (1562° F.), and after reheating from 675° C. (1247° F.). Since this high nickel percentage almost completely prevents the brittleness of the core, one quenching from about 700° C. (1292° F.) is in most cases sufficient.

**Chrome Steel.**—Steels with from 1 to 1.2% chromium are sometimes used when an especially hard case is required. This element, however, aids the crystallization of the core and the double quenching is, therefore, absolutely necessary. Chrome-nickel steels with a low chromium content require about the same heat treatment as pure nickel steels.

**Carburizing Materials.**—To convert the surface of wrought iron or mild steel into hardening steel, the present practice is to pack the work in raw bone, leather scrap,

wood charcoal, charred bone or charred leather. In general, the granulated bone may be mixed with an equal bulk of granulated wood charcoal, the granules of each to be of the same size, since should one be finer than the other the finer will settle to the bottom and produce an uneven mixture. Carbon should exist chiefly as fixed carbon, although it is essential that some hydrocarbons or nitrogenous matter be also present to act as carriers of the carbon and to create a more active carburizing atmosphere in the box.

**Bone.**—An analysis of bone yielded: 8.0% carbon; 25.5% volatile matter and hydrocarbons; 3.5% nitrogen; 60% ash; 1.0% sulphur; 2.0% moisture = 100.0%. Alumina, lime, and ammonia were included in the ash, as also 16.0% phosphoric acid. Granulated bone as a carburizer is in common use, but raw bone does not work well for articles that are comparatively weak, and which are to be subjected to strain; raw bone is rich in phosphorus, and phosphorus causes brittleness in steel. Charred bone is to be preferred because the fixed carbon is in a better state for carburizing work.

**Charred Leather.**—69.0% carbon; 15.2% volatile matter and hydrocarbons; 3.8% nitrogen; 3.5% ash; 0.55 sulphur; 8.0% moisture = 100.05%. Alumina, lime, iron and silica were present in the ash, as also 0.10% phosphoric acid. Charred leather contains more fixed carbon than bone, but bone contains more volatile hydrocarbons; the total carburizing matter for each of the respective compositions is practically: Bone = 37%, charred leather, 88%. Sulphur when present in such a quantity as in charred leather is likely to produce deteriorating effects. Charred leather is sometimes objected to as a case-hardening material because it works too actively; Guillet recommends a mixture of 60 parts wood charcoal and 40 parts of barium carbonate, as best to use.

Moisture, when present in amounts over 12%, causes a rough surface to be produced on the work to be case-hardened. This action appears to be intensified by the presence of sulphur.

**Cyanides.**—Carbon does not combine with nitrogen under ordinary circumstances. If, however, they are brought together at very high temperatures in the presence of metals, they combine to form compounds known as cyanides. When refuse animal substances, such as blood, horns, claws, hair, etc., are heated together with potassium carbonate, and iron, a substance known as potassium ferro-cyanide, or yellow prussiate of potash, is formed. When this is heated it is decomposed, yielding potassium cyanide. When this salt is treated with chlorine it is converted into potassium ferrocyanide, or red prussiate of potash.

**The Effect of Nitrogen** (in combination as cyanogen) has been dealt with by recent workers. Charpy, for example, made experiments in an atmosphere of carbon monoxide, together with cyanides, and also in an atmosphere of the same gas, but devoid of nitrogen, the result of which indicated that the presence of cyanides was not essential in case-hardening, and that the case-hardening is produced chiefly by the gases evolved by the case-hardening agents.

**Carburizing Gas.**—The effective power for case-hardening of the following gases, illuminating gas, acetylene, and carbon monoxide, carried out experimentally with each gas alone and also mixed with ammonia in definite amounts, showed that the presence of ammonia facilitates case-hardening in all cases except that of carbon monoxide, which acts as well without it as with the ammonia treatment. Of the three gases studied, the carburizing efficiency is in the following order: Carbon monoxide, acetylene, methane. Carbon monoxide appears to be the best for case-hardening, as no ammonia seems necessary, and it gives the best penetration in the same time.

By this process the articles to be case-hardened are not packed but simply placed in a cylindrical retort mounted within a suitable furnace, where the articles are heated to, say, 816 to 982° C. (1500 to 1800° F.). Carburizing gas under pressure, 25 pounds per square inch, or even higher, is then introduced and surface carburization of each article begins. The retort is slowly rotated to bring each article in contact with the carburizing gas, the spent gas escaping from the retort according as the carburizing gas is supplied at the other end under pressure.

This operation may be arrested at any point; the contents of the retort are per-

mitted to cool from the carburizing heat to a cherry red and then quenched in a cooling bath, to be afterward tempered as desired.

**Method of Case-Hardening.**—An iron box is used in which the articles are packed in carburizing material; these boxes are made from either cast iron, wrought iron, or low-grade sheet steel. E. R. Markham states that after an experience of many years he has used boxes made of cast iron almost exclusively and with uniformly good results.

In packing a box with articles to be case-hardened, such as bolts, nuts, wrenches, bushings, etc., there is first placed in the bottom of the box a layer of carburizing material about one inch in depth; then a layer of the articles to be case-hardened; the space between each article is to be closely packed with the carburizing material. For small work, several pieces may be loosely wired together and spread out in the packing; the wiring facilitates removal from the box after heating, preparatory to quenching. After the first layer of work has been packed in the box and covered with about an inch of carburizing material, another layer of work is similarly packed and covered, and so on in alternate layers until the box is filled to within about an inch of the top, including an inch layer of carburizer; the lid is then placed on top of the carburizing material, the joint between the lid and the box being luted with fire-clay or asbestos cement to prevent escape of gas from the carburizing material.

**Heating.**—The box packed and luted is now ready for the furnace, the temperature of which should not greatly exceed 426° C. (800° F.). After placing one or more boxes in the furnace the gas flame is increased, the furnace temperature is slowly raised to the carburizing temperature, which may lie between 816 to 982° C. (1500 to 1800° F.). These temperatures should be by pyrometer readings only.

The length of time required to bring the box and its contents up to the furnace temperature is often a matter of judgment based up n previous experience; it may be two hours or more, but timing for carburizing is to begin when the contents of the box have reached the carburizing temperature. After which, for small and medium work, the box may remain in the furnace 4 to 8 hours, depending upon the depth of hardening desired. Markham states that ordinarily carb n penetrates iron at the rate of about ⅛ inch in 24 hours.

**Case-Hardening Temperatures.**—In an article in *Le Génie Civil* (1912), Dr. L. Guillet states that for regular carbon steels the carburizing temperature should be about 850° C. (1562° F.). After carburizing, the objects should be permitted to cool to about 590° C. (1094° F.), or lower. They are then again heated and quenched from a temperature of about 1025° C. (1875° F.) for refining the core, after which they are again heated and quenched from a temperature of 750° C. (1380° F.) for the final hardening. The quenching in both cases is done in water.

Withdrawal test wires are useful in approximating temperatures in the box; these are simply stiff wires passing through the side of box and into the carburizing material. When it is desired to know the temperature of the contents, one of the wires is withdrawn without disturbing the box in the furnace; the color of the wire will give a close approximation of temperature, thus a medium cherry red indicates a temperature of about 677° C. (1250° F.), too low for case-hardening; a bright cherry red indicates a temperature of about 800° C. (1500° F.), a good temperature for small and medium work. Carburization is not effective at temperatures below 760° C. (1400° F.), a full cherry red. The pyrometer will give the temperature of the furnace at the time of the withdrawal of the wire. When the proper temperature has been reached it can be maintained through manipulation of the fuel supply. Uniformity in furnace temperature is of the greatest importance, too high a temperature, or a variable temperature promotes crystallization in the central portion of the work, making it brittle.

**Quenching.**—In a trade catalogue relating to case-hardening furnaces, it is recommended that the boxes taken from the furnace, the covers having been removed, the hardened parts should be dumped upon a perforated screen so that the hardening material shall not adhere to the pieces when they are raked into the water for quenching. The case-hardening material drops through the screen into a can or box placed under it. When this material dries it may be used again, if mixed with fresh material. The screen should be near the shelf of the furnace, at an angle of about 45 degrees,

and attached to the water tank into which the carburized pieces are raked. A jet of cold water should be opened into the tank at the bottom whenever a box is about to be removed from the furnace. A blast of cold air into the water near the bottom of the tank is also an aid.

**Cooling and Reheating.**—If the work to be hardened consists of bolts, nuts, screws, etc., it is satisfactory to dump them into water directly from the furnaces, without any reheating, but in more important hardening the boxes should be allowed to cool down with the work in them, after which they are reheated and hardened in water. The reheating refines the grain of the steel and prevents the formation of a distinct line between the outer hardened case and the soft core.

A still more refined method of case-hardening is to repack the work, after it has been carburized, in old bone, and after heating for two or three hours take it out and dip the pieces in the hardening tank directly as they come from the boxes. This will produce a very fine grain and in many cases prevent warping. If the work is large and it is required to toughen the inner core, it should be reheated to a higher heat than otherwise; than, after dipping, reheat again to 1500 or 1600° F. according to the size of the work, and redip.

Gears and other parts which should be tough, but not glass hard, should preferably be hardened in an oil bath. There is then less liability of warping the work, and the hardened product will stand shocks and severe stresses without breakage. Cottonseed oil is the best hardening medium to be used in this case.—*R. H. Grant.*

**Case-Hardening Mixture.**—The following formula is in use at the Juniata Shops of the Pennsylvania R.R. Co.

11 pounds prussiate of potash.
30 pounds sal soda.
20 pounds coarse salt.
6 bushels powdered charcoal (hickory preferred).

The whole is mixed thoroughly, using about 30 quarts of water in the mixing; the above quantity is sufficient to harden three boxes of material containing the following parts: 2 links, 2 link blocks, 2 link-block pins, 2 valve-rod pins, 4 knuckle-joint pins, and 24 gibs for spring rigging.

The box required to hold these parts measures 40 inches long, 16 inches wide, and 12 inches deep. In packing, the bottom of the box is covered to a depth of 2 inches with the compound; the parts to be hardened are placed solidly, so that the compound is in contact with the bottom surface of the work; care is taken that the work does not touch the sides of the box or other pieces in the box. After the first layer of the material is placed, it is covered on all sides and on the top with the compound, and is solidly packed. After which the same process may be repeated, being sure to have sufficient compound between the two layers to prevent contact. There should not be less than 2 inches of compound on top of the last layer. The lid which fits inside the box is then thoroughly sealed with a luting of fire-clay.

When in the furnace, the box rests on rollers to allow the flames to pass under it. The furnace is kept at a bright red heat, but not hot enough to scale or blister the work; the time required to harden them properly is fourteen hours; then quenched in an overflowing tank supplied with cold water.

**The Cyanide Process of Case-Hardening.**—Pure cyanide of potassium, when melted in a crucible furnace, furnishes a rapid method for case-hardening large quantities of thin machinery steel parts. By this method the pieces to be hardened are placed in a wire basket, and when the cyanide has been melted, the basket containing the work is lowered into the liquid and left for a short time—sometimes twenty minutes—depending on the depth of the case required. The pieces are then dumped into a bath of cold water.

While this method is very rapid and uniform, it is objectionable because cyanide of potassium is a deadly poison, and when it is used, the furnace must always be connected with the chimney so that the fumes can be carried away. The furnace is almost identical with the single crucible furnace, but is made low for convenience in placing a sheet-iron hood on top when used for cyanide hardening. The pot is of cast iron

or pressed steel, gas is used for fuel, the cyanide can be raised to the desired temperature quickly and kept there with little attention on the part of the operator.

**Case-Hardening for Colors.**—In order to produce colors on iron and steel it is necessary that the surfaces be polished, and usually the finer the polish the better the colors. The metal must be entirely free from grease and dirt.

Certain carbonaceous materials will not produce colors. Raw bone is not used, neither is prussiate of potash; but cyanide of potassium works satisfactorily; charred bone produces a nicely colored surface, while charred leather is one of the best agents for this purpose. Any carbonizer that is to be used for colored work must be kept clean and dry, since moisture will generate steam and prevent good results.

When articles must have a deeply hardened, colored surface, it is necessary to undergo several operations. Markham suggests a large hexagon nut, as an example, in which the depth of penetration is specified, and that the walls of the hole must not be hard, so that threads can be cut after the nut is hardened.

The nuts must be packed in coarse granulated bone, run for a period of ten to twelve hours and allowed to cool in the box. Then repack in the same manner and run for the same length of time. After cooling they are repacked in charred bone, to which is added a small amount of charred leather, and run for three or four hours after they become red-hot. While the first two carbonizing heats are fairly high, viz., a high red or low yellow, the last heat which is to produce colors must be a low red. After they have been in the fire the proper length of time, remove them one at a time and harden in a bath of clear water.

To cause the walls of the holes to be soft, each of the nuts is to be provided with two plates of such size as to protect the top and bottom surfaces of the nut around the holes for a distance equal to the depth of thread.

It is necessary to work quickly when handling pieces that are to be colored, as exposure to the air for any great length of time will prevent colors; the oxygen in the air attacks the surfaces and causes oxidation. When comparatively small pieces are to be colored, and the penetration need not be deep, the articles may be packed in charred bone, charred leather, or a mixture of the two, run at a low red until the proper penetration is insured, then dumped direct into the bath.

When large quantities of work are to be colored, a bath having a continuous water supply from a pipe at the bottom, together with a jet of air introduced with the water, gives good results. If the work comes in contact with air before entering the water, good colors cannot be produced; but air in the water tends to produce better colors than can be obtained without it.

**Cyanide Coloring.**—The method frequently employed consists in melting cyanide of potassium in a cast-iron crucible, suspending the articles in the cyanide, which is at red heat. The articles are allowed to remain there until they attain a low red, when they are removed, one at a time, and dipped into an overflowing bath of clear water.

It is sometimes desirable to color surfaces, and yet not have the pieces hardened. This may be accomplished by what is commercially termed 50% fused cyanide, and if stock is used that will not harden of itself, beautifully colored soft surfaces result. The treatment is exactly the same as where the regular commercial cyanide is used. The use of the fused cyanide is recommended where the pieces must be straightened or bent to some desired form after coloring.

# SECTION 9

## NON-FERROUS METALS AND ALLOYS

Non-ferrous alloys used in engineering work are commonly divided into three clásses: (1) Bronzes or alloys consisting chiefly of copper and tin, though sometimes containing small proportions of other metals and non-metals in combination. Thus, gun metal originally consisted of 90% copper and 10% tin; the later alloys contain about 88% copper; 10% tin; 2% zinc, with perhaps a small percentage of iron and of lead. A bronze is sometimes given the name of an added element which imparts a special quality to the alloy, for example: Phosphor-bronze is ordinary bronze to which phosphorus has been added either as phosphor-copper or phosphor-tin. Manganese bronze is an alloy of bronze and ferro-manganese. Silicon bronze is an alloy of copper and tin containing silicon. Alloys with about 9.0% tin show the greatest strength of all bronzes, and alloys with about 15.0% tin possess the greatest hardness and strength.

(2) Brasses or alloys consisting chiefly of copper and zinc; most varieties, however, contain other metals, such as lead, tin, and iron. The English standard brass consists of 66.6% copper; 33.4% zinc. The normal composition of brass for the United States Navy is 62% copper; 1% tin; 37% zinc, with which are also incorporated small percentages of iron (0.06%) and lead (0.3%) as a maximum. The physical properties of brass vary according to the relative quantities of copper and zinc, that alloy containing about 28.5% zinc showing the greatest strength. Complex brasses are copper-zinc alloys to which other constituents have been purposely added, for example: brass with lead; brass with tin; brass with manganese; brass with aluminum, etc.

Nickel alloys form a class distinct from ordinary bronzes and brasses. A composition of copper, nickel, and zinc widely used in the arts is commonly known as German silver, sometimes as nickel silver. German silver is superior to brass, as regards strength, hardness, and power of resisting chemical influences. For engineering use the United States Navy composition is 64% copper; 20% zinc; 16% nickel. For commercial use: 46% copper; 34% nickel; 20% zinc is considered the best.

(3) White metals for bearings commonly known as anti-friction metals include in their composition copper, tin, antimony, zinc, and lead. The alloys, however, seldom consist of more than three metals; of the alloys containing copper, Babbitt metal is probably the best known. The following formula has been attributed to him: Melt together 4 pounds copper; 8 pounds antimony; 24 pounds tin; this is called the hardening compound. For each pound of the hardening compound add 2 pounds additional of tin. A good alloy for low pressures and medium speeds consists of: 6.0% tin; 16.0% antimony; 78.0% lead. An alloy for light pressures and slow speeds may consist of 10.0% antimony; 90.0% lead. The melting point of each of the above anti-friction metals is below red head; they can be readily melted in an iron ladle in an ordinary forge fire.

## NON-FERROUS METALS

Non-ferrous metals are those which do not partake of the nature of iron. The metals have been conveniently grouped by chemists according to their base-forming properties; this grouping is too elaborate for our present purpose; we have therefore shortened it somewhat as follows, limiting the groups to the non-ferrous metals used in engineering:

**Copper Group.**—Copper, Cu. Atomic weight, 63.6. Specific gravity, 8.93 = 554 pounds per cubic foot = 0.321 pound per cubic inch. Specific heat, 0.093. Melting point, 1083° C. (1981.5° F.). Tenacity, 27,800 pounds per square inch. Fracture, fibrous; color, red.

**Mercury.**—Symbol Hg. Atomic weight, 200.6. Specific gravity, 13.59 = 848 pounds per cubic foot = 0.491 pound per cubic inch. Specific heat, 0.032. It is liquid at ordinary temperatures. It unites with most metals forming amalgams.

**Lead.**—Symbol Pb. Atomic weight, 207.1. Specific gravity, 11.37 = 708 pounds per cubic foot = 0.410 pound per cubic inch. Specific heat, 0.031. Melting point, 327.4° C. (621.1° F.). Tenacity varies, averages about 2,000 pounds per square inch. Color a bluish-gray.

**Bismuth.**—Symbol B. Atomic weight, 208.0. Specific gravity, 9.80 = 612 pounds per cubic foot = 0.354 pound per cubic inch. Specific heat, 0.031. Melting point, 271° C. (520° F.). Color, grayish white. It has the property of expanding in the act of solidifying. This metal is used in the preparation of fusible alloys.

**Tin Group.**—Tin, Sn. Atomic weight, 119.0. Specific gravity, 7.29 = 455 pounds per cubic foot = 0.263 pound per cubic inch. Specific heat, 0.055. Melting point, 231.9° C. (449.4° F.). Tenacity, 3,500 pounds per square inch. Fracture fibrous. Color, grayish white. Tin is an inferior conductor of heat and electricity.

**Antimony.**—Symbol, Sb. Atomic weight, 120.2. Specific gravity, 6.71 = 418 pounds per cubic foot = 0.242 pound per cubic inch. Specific heat, 0.051. Melting point, 630° C. (1166° F.). It can be distilled at white heat. When heated to a sufficiently high temperature in the air it takes fire and burns. Ordinary commercial antimony is often very impure, containing iron, lead, arsenic, and sulphur, and is called "regulus of antimony." It is hard and brittle, has a silver-white color, and a high metallic luster.

**Arsenic.**—Symbol, As. Atomic weight, 75.0. Specific gravity, 5.67 = 353 pounds per cubic foot = 0.0204 pound per cubic inch. Specific heat, 0.081. Melting point, 850° C. (1560° F.). It can be volatilized without melting. At red heat it burns with a bluish flame, and the vapor given off has the odor of garlic. The metal has a brilliant, dark steel-gray color, and metallic luster. It is a poor conductor of heat and electricity.

**Iron Group.**—Iron, Fe. Atomic weight, 55.8. Specific gravity, 7.86 = 490 pounds per cubic foot = 284 pounds per cubic inch. Specific heat, 0.110. Melting point, 1520° C. (2768° F.). Iron is now included in the composition of many of the brass alloys because it imparts to the resultant metal increased hardness, elasticity, and tenacity, important examples of which are Sterro metal; Aich's metal; Delta metal; Admiralty metal; and nearly all the brass for the United States Navy.

The constitution of the iron brasses has not been sufficiently investigated, but when present in small amounts the iron enters into the alloy in the form of a solid solution and does not form, according to Law, definite chemical compounds. When more than about 2% of iron is present a compound of iron and zinc is formed.

**Ferro-manganese.**—Iron and manganese will combine in nearly all proportions up to 80% manganese, or even higher. Mr. P. M. Parsons, in developing his manganese bronze, melted the ferro-manganese in a separate crucible, which was added to the copper when in a melted state. The effect of this combination is similar to that produced by the addition of ferro-manganese to the decarburized iron, in a Bessemer converter; the manganese in a metallic state having a great affinity for oxygen cleanses the copper of any oxides it may contain, by combining with them and rising to the surface in the form of slag, which renders the metal dense and homogeneous. A portion of the manganese is utilized in this manner, and the remainder, with the iron, becomes permanently combined with the copper, improving and modifying the quality of the alloys, afterward prepared from the copper thus treated.

**Manganese.**—Symbol, Mn. Atomic weight, 55. Specific gravity, 8.00 = 499 pounds per cubic foot = 0.289 pound per cubic inch. Specific heat, 0.120. Melting point, 1225° C. (2237° F.). This metal is obtained principally by the reduction of black oxide of manganese; the resultant metal being in appearance similar to cast iron; it is hard and brittle; it easily oxidizes and must therefore be excluded from the air. It is used as a constituent of some useful alloys, notably iron, steel, and copper.

The important qualities of manganese bronze consist in adding the manganese in its metallic state, in the form of ferro-manganese, to the copper, by which the copper is cleansed from oxides. The amount of manganese required for deoxidizing the copper and for permanent combination with it, having been ascertained by experience, very

slight variations in quantity have a perceptible and ascertained effect in modifying the qualities of alloys produced; thus, toughness can be increased, and hardness diminished, or *vice versa*, at will.

In preparing the ferro-manganese for use, that which is rich in manganese containing, say, from 50 to 60%, is preferred; this is melted with a certain proportion of the best wrought-iron scrap, so as to bring down the manganese to the various proportions required.

**Nickel.**—Symbol, Ni. Atomic weight, 58.7. Specific gravity, 8.8 = 549 pounds per cubic foot = 0.318 pound per cubic inch. Specific heat, 0.108. Melting point, 1452° C. (2646° F.). Nickel is a white metal with a slight cast of yellow. In its ordinary or unrefined condition it is brittle, due to the presence of iron, copper, silicon, sulphur, arsenic, and carbon, but when it contains a small quantity of magnesium or phosphorus it becomes malleable. The magnesium is supposed to reduce the occluded carbonic oxide CO, forming magnesia, and to cause the carbon to separate out as graphite. Aluminum is now generally used instead of magnesium in refining nickel. Nickel unites readily with most metals forming valuable industrial alloys. Argentan or German silver is an alloy of copper, zinc, and nickel: The proportions for the United States Navy are 64% copper; 20% zinc; 16% nickel. Benedict nickel is 84 to 86% copper; 16 to 14% nickel.

**Cobalt.**—Symbol, Co. Atomic weight, 59. Specific gravity varies, but averages 8.50 = 530 pounds per cubic foot = 0.307 pound per cubic inch. Specific heat, 0.103. Melting point, 1490° C. (2714° F.). The boiling point is said to be 2200° C. (3992° F.), It is a hard, tenacious metal of silver-white color, occurring in nature, almost always in company with nickel, and, like nickel, preferably forms compounds which are analogous to ferrous compounds.

Alloying aluminum with 9 to 12% cobalt improves its properties, but it is still deficient in mechanical strength owing to the coarse crystalline structure. This defect can be overcome by addition of a small proportion of tungsten or molybdenum, yielding alloys having a tensile strength three times that of pure aluminum. The best results are said to be obtained with: 0.8 to 1.2% tungsten; 8.0 to 10.0% cobalt; or 0.6 to 1.0% molybdenum; 9.0 to 10.0% cobalt. The forging and rolling qualities diminish and the tensile strength increases with increasing content of tungsten (or molybdenum) and cobalt. The alloys containing tungsten are somewhat harder than those containing molybdenum.

**Zinc Group.**—Zinc, Zn. Atomic weight, 65.4. Specific gravity is not constant, averages about 7.15 = 446 pounds per cubic foot = 0.258 pound per cubic inch. Specific heat, 0.094. Melting point, 419.4° C. (786.9° F.). Its boiling point is variously placed at 906 to 1040° C. (1663 to 1904° F.). It has a highly crystalline structure and at ordinary temperatures is quite brittle. The chief impurities are iron, lead, and arsenic.

Experiments made in Belgium to ascertain the effects of foreign metals on the rolling of zinc showed cadmium to be harmful if above 0.25%, while with 0.5% rolling is impossible. Arsenic present in 0.02% markedly increases the hardness, and with 0.03% the metal is too brittle for practical purposes. Antimony is less objectionable than arsenic, as 0.07% does not increase the hardness; but 0.02% is enough to produce a striated surface on the rolled sheet, which makes it unsalable. Tin is objectionable when over 0.01% and prohibitive at 0.03%. Copper does not harden until it reaches 0.08% and with 0.19% the zinc is unworkable. A permissible maximum of iron is 0.12%, but this is easily reduced in refining. Though 1% to 1.25% of lead does not interfere with the rolling, a slight increase not only seriously affects the malleability, but the excess of lead remains unalloyed and forms patches on the sheet. The presence of two or more impurities together results in a combination of injurious effects of each.

**Cadmium.**—Symbol, Cd. Atomic weight, 112.4. Specific gravity, 8.60 = 537 pounds per cubic foot = 0.311 pound per cubic inch. Specific heat, 0.056. Melting point, 320.9° C. (609.6° F.). It is more volatile than zinc; its boiling point is 766° C. (1411° F.). In color it is tin-white; structure, fibrous; it is harder than tin. As cadmium occurs in zinc ores it is frequently found in commercial spelter, to which it imparts a fine grain; it is not at all injurious, however; according to some authorities it im-

proves brass. The metal is chiefly used for making fusible alloys, and is a constituent of some aluminum solders.

**Magnesium.**—Symbol, Mg. Atomic weight, 24.3. Specific gravity, 1.74 = 107 pounds per cubic foot = 0.062 pound per cubic inch. Specific heat, 0.250. Melting point, 651° C. (1204° F.). It is said to boil at 1120° C. (2048° F.). When heated above its melting point in oxygen or in the air, it takes fire and burns with a bright flame. The metal is of a brilliant white color, but tarnishes when exposed to moist air. At a temperature of 450° C. (842° F.) it can be rolled and worked into a variety of forms. It is sometimes used as an alloy with aluminum.

Magnesium, even in small percentages, improves the mechanical properties of aluminum. The following table indicates to what extent:

Strength of Aluminum—Magnesium Alloys

L. Mach

| Magnesium in Alloy, Description | 2 Per Cent | | 4 Per Cent | | 6 Per Cent | | 10 Per Cent | |
|---|---|---|---|---|---|---|---|---|
| | Tensile Strength, Pounds per Sq. In. | Elongation % | Tensile Strength, Pounds per Sq. In. | Elongation % | Tensile Strength, Pounds per Sq. In. | Elongation % | Tensile Strength, Pounds per Sq. In. | Elongation % |
| Cast in sand | 17,900 | 3.0 | ..... | .... | ..... | .... | 21,400 | 2.4 |
| Cast in chills | 28,600 | 2.0 | 28,600 | 2.0 | ..... | .... | 33,600 | 3.4 |
| Castings, water chilled | 40,000 | 1.0 | ..... | .... | 57,600 | 1.0 | 61,100 | 4.2 |
| Annealed sheet | 25,600 | 18.0 | 28,700 | 8.0 | 28,100 | 17.0 | ..... | .... |
| Hard sheet | 41,300 | 2.7 | 44,900 | 2.1 | 44,100 | 1.0 | ..... | .... |

**Aluminum.**—Symbol, Al. Atomic weight, 27.1. Specific gravity, 2.56 = 160 pounds per cubic foot = 0.092 pound per cubic inch. Specific heat, 0.218. Melting point, 658.7° C. (1217.7° F.). Its boiling point is about 1800° C. (3272° F.). It is a white metal, soft, malleable, and ductile, it flows easily under pressure and can be rolled, hammered, and stamped. The ultimate tensile strength of unworked castings is about 15,000 pounds per square inch, with an elastic limit of about one-half that amount.

Aluminum alloys are largely employed in the manufacture of automobiles and aeroplanes. Owing to its low tensile strength the usefulness of aluminum has not widely extended into the heavier class of engineering work except as an alloy in the various bronzes, brasses, and white metals.

## ALKALINE-EARTHY METALS

The metals calcium, barium, and strontium are called the metals of the alkaline earths. **Calcium,** Ca: Calcium is found in nature in the form of carbonates, as limestone, marble, chalk. It also occurs in the form of sulphate as gypsum; in the form of phosphate, of which bones contain a large proportion; calcium fluoride occurs as fluor-spar, much used in metallurgical operations, as it melts readily and does not act upon other substances easily, serving as a liquid medium in which reactions take place at high temperatures; when used for this purpose it is called a flux.

**Barium,** Ba. Barium sulphate is known to mineralogists as barite, barytes, and heavy spar. Barite is chiefly used for paint in place of white lead and zinc white. The metal is obtained through electrolysis of the molten chloride of barium; its only use is for experimental purposes in the laboratory.

**Strontium,** Sr. A pale yellow metal known chiefly through its salts. It occurs in nature in the form of sulphate, as celestite, also in the form of carbonate, as strontianite. Strontium metal is isolated by the action of an electric current on the molten

chloride. It is oxidized by contact with the air; it decomposes water rapidly with evolution of hydrogen. Strontium nitrate, Sr $(NO_3)_2$, is made for the purpose of preparing a mixture known as Bengal-fire, which burns with a brilliant red light.

## ALKALI METALS

These include lithium, sodium, potassium, rubidium, caesium, ammonium.

**Sodium,** Na. Atomic weight, 23. Specific gravity, 0.97. Specific heat, 0.290. Melting point, 97.5° C. (207.5° F.). It volatilizes, forming a dark blue vapor. Sodium is used for the preparatlon of aluminum, magnesium, boron, and silicon. It is also used, in combination with mercury, as sodium amalgam.

**Potassium.**—Symbol, K. Atomic weight, 39.1. Specific gravity, 0.86. Specific heat, 0.170. Melting point, 62.3° C. (144° F.). It decomposes water with evolution of hydrogen which burns in the air; in consequence of this action upon water it can not be kept in the air, but under some oil, as petroleum, upon which it does not act. Potassium cyanide is used as a flux because of the readiness with which it reduces many metallic compounds when mixed with carbonate of soda.

## NON-METALS

The non-metals commonly met with in the manufacture of non-ferrous alloys are:

**Boron,** B.—This non-metal belongs to the same family as aluminum, but it differs from it in that its oxide is acidic, while that of aluminum is basic. It is used as a deoxider for copper, with which it does not combine. When heated boron loses all its hydrogen in the form of water, and boric oxide or boron trioxide, is left. By melting aluminum and boron trioxide together at a high temperature, the latter is reduced, and the boron thus formed is dissolved in the molten aluminum, from which, on cooling, it is deposited in crystals.

**Carbon,** C.—A non-metallic element distinguished by the large number of the compounds into which it enters. Uncombined, it occurs in nature as diamond and as graphite. In the latter form it is used in the manufacture of crucibles, because of its infusibility and its non-tendency to form fusible slags with acid or basic substances. It will combine with oxygen at high temperatures and form carbon dioxide, or carbon monoxide, but it will not melt, nor will it vaporize. The abstraction of oxygen from compounds by means of carbon may be illustrated in the case of powdered copper oxide when mixed with powdered charcoal, and the mixture heated in a tube, carbon dioxide is given off and the copper is left behind. Charcoal and coke are nearly pure carbon with a little earthy matter, which is left as ash after burning.

**Hydrogen,** H.—This is the lightest substance known; in relation to other gases its specific gravity is 1.000. It differs from other non-metals in not generally uniting with metals to form compounds. A number of metals have the power to absorb a large quantity of hydrogen when they are heated to red heat in the gas; thus palladium, which under the most favorable conditions takes up something more than 935 times its own volume of hydrogen. Aluminum has a marked capacity for occluding hydrogen gas.

**Lime, Calcium oxide,** CaO.—Lime is made from calcium carbonate or limestone by burning in a kiln, expelling its contained moisture and carbon dioxide, leaving as a product lime an infusible compound strongly basic in character but capable of forming a fusible compound with silica and other acid bodies. When limestone is properly burned it becomes the quicklime of commerce. Hydrated lime is prepared by slacking the quicklime in water, thoroughly incorporating the lime and water into a paste, which may be dried and powdered for the market. As a flux, lime combines with silica and the silicates, and is useful in counteracting the effects of sulphur and phosphorus.

**Nitrogen,** N.—Nitrogen does not combine with any element except at a very high temperature. It does not support combustion. In the air it serves the useful purpose of diluting the oxygen; the two gases are not chemically combined, simply mixed. Nitrogen is found in combination in a large number of substances in nature, among which are potassium nitrate, K $NO_3$, commonly known as niter or saltpeter, largely

used as an oxidizing agent; potassium cyanide, KCN, used as a flux on account of the facility with which it fuses, and the readiness with which it reduces many metallic compounds when mixed with carbonate of soda. The limit of reduction of nitrogen compounds is ammonia, $NH_3$, and of oxidation, nitric acid, $HNO_3$.

**Oxygen,** O.—Under suitable conditions as to temperature oxygen will combine with all known elements except fluorine. When its action is rapid and accompanied by an evolution of heat and light the process is called combustion; when the combination takes place slowly without evolution of light the process is called oxidation. The compounds of oxygen with other elements are called oxides, the name of the element with which the oxygen is combined being prefixed, as iron oxide, zinc oxide, etc. An oxide which forms an acid when dissolved in water is called an acidic oxide, such as carbonic acid, silica; an oxide of a base-forming element when dissolved in water will form a basic oxide, such as calcium oxide, potassium oxide, etc. Acidic oxides are chiefly oxides of the non-metals; basic oxides are chiefly oxides of the metals. Water is the connecting link between the oxygen acids and bases.

**Phosphorus,** P.—A soft yellowish-white non-metallic element having a powerful affinity for oxygen. It is obtained from the animal kingdom, as from bones, and from the mineral kingdom, as from calcium phosphate. It combines with oxygen in two proportions, forming oxides of phosphorus; one of these oxides unites with bases forming phosphates. When it occurs in a metal it is usually as a phosphide, but the occurrence in the slag from any metal is as a phosphate. Phosphorus unites both with copper and tin, forming the alloys known as phosphor-copper and phosphor-tin. As a deoxidizer the action of phosphorus in copper is to reduce any oxide present, forming an oxide of phosphorus, which, by reason of its acid character, combines with any basic metallic oxides also present, forming phosphates, and these pass into the slag, the immediate effect of which is to give the molten metal greater fluidity; it is thus conducive to sound castings.

**Plaster of Paris. Calcium Sulphate,** $CaSO_4$.—The principal natural variety of this mineral is gypsum, which, when heated to 100° C. (212° F.), or a little above it, loses nearly all its water and forms a powder known as plaster of Paris. It has been used with success as a flux when melting washings, grindings, etc., in brass foundry practice; its action upon this almost refuse material is to dissolve the foreign matter in the crucible, passing it into the slag, and leaving a comparatively clean molten metal at the bottom of the crucible.

**Silicon,** Si.—This mineral occurs chiefly in the form of silica $SiO_2$, as quartz or as common sand; it also occurs in combination with oxygen and several of the common metallic elements, such as sodium, potassium, aluminum, and calcium as silicates. Silica is a slag forming substance, and is therefore much used as a flux. The action of silicon on copper is that of a deoxidizer and as a flux in the removal of metallic oxides during the process of melting. Some of the silicon enters into combination with the copper-forming cupro-silicon; the quantity is not large, but it has the effect to increase the tensile strength of copper-tin alloys; such alloys are known as silicon-bronzes.

**Sulphur,** S.—A pale yellow non-metallic crystalline element which combines readily with most metals forming compounds called sulphides which are analogous to the oxides. When heated together with copper, or lead, a combination takes place with evolution of heat and light. Sulphur will combine with copper, forming cuprous sulphide, $Cu_2S$; it will also combine as cupric sulphide, CuS; when heated, cupric sulphide loses half its sulphur, and is converted into cuprous sulphide. The principal form (galena) in which lead occurs in nature is sulphide, Pbs. The litharge of commerce is lead oxide PbO; when this is heated with sulphides, sulphurous acid is volatilized and an alloy of the metal with lead is formed. Sulphur, present as an impurity in metals to be made into alloys, has a reducing effect and assists the reducer in the flux.

## NON-FERROUS ALLOYS

The properties of alloys in general, as given below, are an abstract from the Report of the United States Board to test iron, steel, and other metals, of which R. H. Thurston was chairman.

**Physical Properties of an Alloy.**—It is impossible to predict from the character of two metals what will be the character of an alloy formed from given proportions of each. In most cases, however, it will be found that the hardness, tenacity, and fusibility will be greater than the mean of the same properties in the constituents, and sometimes greater than in either, the ductility is usually less, and the specific gravity is sometimes greater and sometimes less.

It is not a matter of indifference in what order the metals are melted in making an alloy. Thus, if we combine 90 parts of tin and 10 of copper, and to this alloy add 10 of antimony; and if we combine 10 parts of antimony with 10 of copper, and add to that alloy 90 parts of tin, we shall have two alloys chemically the same, but in other respects—fusibility, tenacity, etc.—they totally differ.

**Chemical Nature of Alloys.**—Metals in forming alloys are governed by the greater affinities which some of them manifest for each other; this in some measure proves that alloys are not mechanical mixtures, but definite chemical compounds.

Matthiessen experimented on upwards of 250 alloys, all made of purified metals. The results of his investigations may be summed up in the following classification of the solid alloys, composed of two metals, according to their chemical nature:

1. **Solidified Solutions of One Metal in Another.**—The lead-tin, cadmium-tin, zinc-tin, lead-cadmium, and zinc-cadmium alloys.
2. **Solidified Solutions of One Metal in the Allotropic Modification of Another.**—The lead-bismuth, tin-bismuth, tin-copper, zinc-copper, lead-silver, and tin-silver alloys.
3. **Solidified Solutions of Allotropic Modifications of the Metals in Each Other.**—The bismuth-gold, bismuth-silver, palladium-silver, platinum-silver, gold-copper, and gold-silver alloys.
4. **Chemical Combinations.**—The alloys whose composition is represented by $Sn_5Au$, $Sn_2Au$, and $Au_2Sn$.
5. **Solidified Solutions of Chemical Combinations in One Another.**—The alloys whose composition lies between $Sn_5Au$ and $Sn_2Au$, and $Sn_3Au$ and $Au_2Sn$.
6. **Mechanical Mixtures of Solidified Solutions of One Metal in Another.**—The alloys of lead and zinc, when mixture contains more than 1.2% lead or 1.6% zinc.
7. **Mechanical Mixtures of Solidified Solutions of One Metal in the Allotropic Modification of the Other.**—The alloys of zinc and bismuth, when the mixture contains more than 14% zinc, or 2.4% bismuth.
8. **Mechanical Mixtures of Solidified Solutions of the Allotropic Modifications of the Two Metals in One Another.**—Most of the silver-copper alloys.

**Specific Gravity.**—The specific gravity of an alloy is rarely the mean between the densities of each of its constituents. It is sometimes greater and sometimes less, indicating, in the former case an approximation, and in the latter case a separation of the particles from each other in the process of alloying. The specific gravity of an alloy should not be calculated from the weights, but should always be calculated from the volume. The correct rule for this purpose is that given in Ure's Dictionary of Arts, Manufactures, and Mines, which is: Multiply the sum of the weights into the products of the two specified gravity numbers for a numerator, and multiply each specific gravity number into the weight of the other body and add the products for a denominator. The quotient obtained by dividing the said numerator by the denominator is the truly computed mean specific gravity of the alloy.

$$M = \frac{(W - w)\ Pp}{Pw - pW}$$

where M is the mean specific gravity of the alloy, W and w the weights, and P and p the specific gravities of the constituent metals.

The following list of alloys whose density is greater or less than the mean of their constituents, is given by several writers: Alloys, the density of which is greater than the mean of their constituents: Copper and zinc; copper and tin; copper and bismuth; lead and antimony; platinum and molybdenum. Alloys, the density of which is less than the mean of their constituents: Iron and bismuth; iron and antimony; iron and lead; tin and lead; nickel and arsenic; zinc and antimony.

**Fusibility.**—In nearly all cases the fusing point of an alloy is lower than the mean of its constituent metals, and in some instances, as in the so-called fusible alloys, it is lower than that of either. The cause of this fact has not been definitely ascertained. Matthiessen says that the low fusing points admit of explanation by assuming that chemical attraction between the two metals comes into play as soon as the temperature rises, and the moment the smallest portions melt, then the actual chemical compound is formed which fuses at the lowest temperature, and then acts as a solvent for the particles next to it, and so promotes the combination of the metals where this can take place.

**Liquation.**—Many of the alloys exhibit the phenomena of liquation, or separation of the mass of melted metal in the act of solidification into two or more alloys of different composition. The resulting alloy or mixtures of alloys are consequently deficient in homogeneity. The causes of this separation are as yet but imperfectly understood. Bronze alloys, such as gun-metal, are said to have liquation diminished by rapid cooling. When the mass is cooled slowly, bronze castings often show in the interior what are called spots of tin, but what are really spots of a white alloy of copper and tin, containing a larger percentage of tin than the average of the whole casting.

**Specific Heat.**—M. Regnault determined the specific heat of two classes of alloys: First, those which at 100° C. (212° F.) are considerably removed from their fusing points; and, secondly, those which fuse at or near 100° C. (212° F.). The specific heats of the first series were remarkably near to that calculated from the specific heats of the component metals, so that he announced the following law:

The specific heat of the alloys at temperatures, considerably removed from their fusing point, is exactly the mean of the specific heats of the metals which compose them. The mean specific heat of the component metals is that obtained by multiplying the specific heat of each metal by the percentage amount of the metal contained in the alloy and dividing the sum of the products for each alloy by 100.

**Eutectic Alloys.**—When a molten alloy of two or more metals cools to solidification it does not do so as a whole, at a definite temperature, but one of the metals will solidify first, separating itself from the more fusible alloy or metal, which afterward solidifies at a lower temperature. This separation effects a change in the composition of the remaining alloy, if the original alloy consisted of three metals; or the liquid metal remaining, if it consisted originally of two metals; the separation in either case continues only on a falling temperature. The ratios in which the constituent metals unite to form the alloy possessing the lowest melting-point are never atomic ratios, and when metals do unite in atomic ratios the alloy produced is never eutectic, that is, it does not have a minimum solidifying point.

The term eutectic has been specifically applied to a mixture of metals in such proportions that the fusing point is lower than that of either of the constituents themselves. Alloys are always regarded as eutectic compounds.

The mechanical properties of eutectic alloys are dependent on the manner in which the component crystals are interlocked. In some eutectics neither constituent exhibits definite crystal outlines, while in others the crystalline arrangement is due to one of the constituents. This is the case in alloys of copper and antimony in which the antimony determines the crystalline arrangement, and it would seem to be associated with the power possessed by some substances of forming crystal skeletons rather than small crystals. C. H. Desch found that free antimony is able to form fern-like growths, and in the presence of excess of antimony. The eutectic structure has a definite orientation to these crystals. In the copper-silver alloys, and in copper containing oxygen the small red-like crystallites are rounded. This is considered to be due to the action of surface tension at the time of solidification.

**Occlusion.**—The gas-absorbing power of molten copper increases, in general, with the temperature up to a certain point, also with increasing purity of the metal; the presence of platinum or nickel has a favorable influence on the absorption. The disintegration of copper, which takes place during solidification, has been traced to occluded sulphur dioxide $SO_2$, which is formed by oxidation of the sulphur present, and given up during solidification. Up to 1500° C. (2732° F.) the absorption increases with the temperature. The fact that the gas causes the metal to "spit" and become spongy

during solidification, and that a considerable quantity of gas is still retained in the cold metal, shows that absorption and not adsorption effects are concerned. Sulphur dioxide does not diffuse through solid copper below 1000° C. (1832° F.). Estimations of the lowering of freezing point produced by the oxide and sulphide show that the compounds occur as copper sulphide and cuprous oxide, and that their solubilities are more than sufficient to account for the absorption of sulphur dioxide by decomposition and chemical reaction.

**Oxygen.**—When oxygen is in solution in copper, the dissociation pressure is lowered, so that, at 1600° C. (2912° F.), no thermal decomposition of the dissolved oxide occurs, and the absorption of $O_2$ at this temperature is not a physical solution but a chemical combination.

Evidence of the solubility of hydrogen in copper is given by surface disintegration and blister-like structure assumed by the metal during solidification after exposure to this gas. An absorption of $H_2$ in, and diffusion through, copper has been detected at 650° C. (1202° F.). Up to 1500° C. (2732° F.) the absorption increases almost linearly with the temperature; when the melting point is reached a sudden increase occurs. The conductivity of copper is not affected by the dissolved hydrogen. On heating copper containing oxide in a hydrogen atmosphere, the gas penetrates the metal and reduces the oxide with formation of water, which escapes by disintegrating the metal and rendering it unsuitable for further mechanical working.

A slight solubility of carbon monoxide in copper has been shown by changes in the density produced in the metal by its presence, by the blister-like structure it imparts to the metal, by spectrum analysis, and by direct measurement. A small quantity of gas appears to have a marked influence on the physical properties of the refined metal.

**Deoxidizing Copper.**—Silicon in the form of silicon-copper is a good deoxidizer of copper, whether the copper charge is all new metal, or all scrap, or any proportion of either. The silicon-copper should be added when the copper is sufficiently hot to pour, and the metal should be removed from the furnace 10 minutes after the silicon has been added. Use charcoal as a cover on the copper, melt quickly, and do not keep it in the furnace longer than necessary. There is no gain in using more than 2.0% of silicon-copper and, if the copper is well melted, 1.0% will be sufficient to make solid castings.

The effect of silicon on yellow brass is similar to that of aluminum, that is, it adds fluidity and gives the metal the same appearance. However, while aluminum can be used in a leaded alloy, silicon cannot, as it causes excessive drossing. The effect of silicon on a bronze mixture 85% copper, 11% tin, and 4% lead, would be to produce so much dross that the metal could not be used for sand castings. Although the conductivity of the metal is not as high as when magnesium is used, the silicon will produce a more reliable casting.—*Foundry.*

## THE POROSITY OF BRASS CASTINGS

Some metals absorb gases so easily when heated that they cannot be cast without the addition of some deoxidizing agent. This is the case with copper, no matter how solid the copper may be before it is melted; if poured into the molds without treatment, they only remain full a short time before the copper rises in the sprues and overflows on to the floor. In every case the castings will be found honeycombed whenever this occurs. It is necessary therefore to alloy some other metal or element having a greater affinity than copper for oxygen, to form an oxide that either rises to the surface as a slag, or escapes into the atmosphere as a vapor. The latter occurs when zinc is added to molten copper; phosphorus forms a slag of ever-changing form and position on the surface of the metal.

When copper is melted under charcoal, the quantity of gas absorbed is not large, the metal, when cooled, possesses a metallic appearance, even though not solid; but if heating were continued sufficiently long, the copper would lose its metallic characteristics, passing into an oxide; this explains why it is necessary to protect copper from the atmosphere while in the furnace.

However carefully copper may be melted, sufficient gas is absorbed to prevent its being cast pure; the copper must therefore be deoxidized; the substances often used in making brass or bronze are zinc and phosphorus. Tin is not an active deoxidizer, so while alloys of copper and tin can be made without the addition of any other element, they are so liable to porosity that it is always desirable to add either zinc or phosphorus. A familiar example of the use of zinc to prevent porosity is the well-known alloy—copper 88%, tin 10%, zinc 2%, and even in this alloy there is a tendency to porosity, because of the small percentage of zinc. Phosphorus is a much more active deoxidizing agent than zinc, and if the 2% zinc in the above were replaced by 2% of 15% phosphor-copper, it would make an excellent phosphor-bronze. As a preventive of porosity, phosphorus is not a specific, and phosphor-bronze may produce spongy castings when carelessly melted. It is, however, the best agent for deoxidizing the metal; defective castings should be remelted and run into ingots with the addition of 5% of 15% phosphor-copper. These ingots can be melted with new metal without producing porosity. The oxidation of copper is largely prevented by the use of fluxes, and one of the best of these is common salt. It should be added at the beginning of the heat, after the metal has begun to melt; the cold additions, which may protrude above the charcoal, should be pushed into the liquid metal as they become hot.—*C. Vickers*.

## FLUXES USED IN MELTING NON-FERROUS METALS

A flux is a substance used for cleansing a mass of molten metal, by the removal of such foreign ingredients as can readily be fused into a slag. A flux must therefore melt at a temperature below that of the molten metal and it must not act injuriously upon the metal to be cleansed; its proper function is that of a liquid medium in which reactions take place at high temperatures. The selection of a flux will vary with the metal to be cleansed and the properties of the substances to be removed. If the impurities are of an acid nature, a basic or neutral flux will be required. So also, an acid flux will be required if the impurities are basic in their character.

The fluxes employed in brass foundry practice formed the subject matter of a paper prepared by Erwin S. Sperry for the American Brass Founders' Association, 1910, from which the following notes are taken:

In the early days of brass founding two things were guarded jealously: the mixture and the fluxes. Chemists made serious inroads into the mixtures, and their secrecy faded away. The mystery of the fluxes was more difficult to eliminate, as, unlike the castings themselves, they did not go beyond the foundry. In course of time the secret fluxes went the way of the brass mixtures and they became general technical knowledge.

As to the advantage of a flux and whether one is actually necessary, Mr. Sperry believes the flux question to be greatly overdone and imperfectly understood. It is not advisable to go into a detailed enumeration of all the fluxes that can be used in brass melting; it would be of little value. The following fluxes are those which have proved valuable, and the manner in which they should be used.

**Copper.**—Probably more fluxes have been proposed or used for copper than for any other one metal or its alloys because copper cannot be melted alone and yield sound castings. In the selection of a flux for copper it should be known whether pure copper castings are to be made or whether it is to be alloyed to make brass or bronze. To make sound copper castings with a flux alone, and without the use of "physic" like silicon-copper, magnesium or similar materials (which, strictly speaking, are not fluxes), is a difficult matter. For this purpose yellow prussiate of potash (potassium ferrocyanide) is excellent. With it sound copper castings can be made, but better results may be obtained by the usual deoxidizing agents, such as silicon-copper, magnesium, and phosphorus.

In melting copper for producing brass or bronze there is nothing better than common salt. Its value lies in that it possesses the property of reducing any oxide of copper which may form during the melting; about a handful of salt in a 150-pound crucible is used and is preferably put in after the copper has begun to melt. If the salt is introduced with the copper it melts before the copper, volatilizes, and goes to waste. Too much salt produces a liquid that is apt to penetrate the crucible like fluor-spar, although

not as violently or as rapidly. The theory of the action of common salt seems to be that, at the temperature of the molten copper, it breaks up or dissociates into metallic sodium and chlorine gas. The latter escapes and the sodium performs its work in deoxidizing.

**Brass.**—The flux almost universally employed in brass melting is common salt; its action is to reduce the oxide of copper formed in melting the copper previous to the addition of the spelter. The quantity used is, as already stated, about a handful to a 150 pound crucible, added after the copper begins to melt. When the right conditions have been produced there will be a little slag on the top of the brass when it is skimmed. It is of note that, although every brass rolling mill uses salt in brass melting, few brass founders who make sand castings employ it. Mr. Sperry advocates its use under all conditions, as it is theoretically correct and has been found by actual practice to improve the quality of brass and is so cheap that the cost of the brass is not appreciably increased. Every brass founder should use it, whether he makes new metal or melts scrap, as the character of the castings will be improved.

**Bronze and Composition.**—What has been said about the use of common salt in melting yellow brass applies equally well to composition or bronze, and it is used in identically the same manner and in the same quantities. It makes no difference whether phosphorus or other deoxiding agents are employed, the salt is used just the same.

**German Silver.**—This is such a refractory material in the rolling mill that much time and thought have been given the subject of a suitable flux for it. The bulk of German silver manufactured in the United States is made by two concerns. One uses a flux in making it, while the other uses none. The concern which uses no flux at all has a little better reputation, and they have the more particular trade; examples, which indicate that fluxes do not constitute the "secret" of making German silver. Mr. Sperry demonstrated in practice that a mixture of nitrate of soda or the nitrate of potash (nitre), mixed with black oxide of manganese and used as a flux on copper, will introduce metallic manganese into the copper, showing a reducing action. The probable reason for the action of the flux is that a slight amount of manganese is thus introduced. Metallic manganese has come into use as a deoxidizing agent for German silver and similar nickel alloys, which is preferable to introducing manganese through the agency of a flux; the results are positive, certain, and predetermined amounts of manganese always can be added. While its use has been attended with excellent results, it also seems to be the natural deoxidizing agent for nickel and nickel alloys. In making German silver common salt is used in the same manner, and with the same results as those obtained in brass and bronze.

**Nickel.**—The flux used by makers of nickel anodes has proved a good one. It is composed of lime, 3 parts; fluor-spar, 1 part. Slake the lime as though mortar were to be made; then stir in the fluor-spar and allow it to become solid. It is then broken up into small pieces for use. This flux has been found particularly serviceable in melting old anodes, as it dissolves any earthy matter that may be on them. It is used for both new and old material, and may be called the standard flux for nickel. The proportions used are about a pint or a good handful for new nickel, and twice this quantity for old material.

Fluor-spar alone is a good flux but it becomes very fluid when melted and rapidly attacks a crucible. It seems to soak in and dissolve out the clay from the crucible mixture and leave nothing but the graphite. The use of lime with the fluor-spar is to increase the melting point so that it will not so readily attack the crucible. Although the fluor-spar is toned down with lime, the flux will still act on the crucible, which will last only five or six heats, but all fluxes act on the crucible to a greater or less extent, otherwise they would not be of value as a flux.

**Washings, Grindings, Etc.**—For use in melting brass, bronze, or composition washings, grindings, skimmings, and similar material, nothing is better than plaster of Paris. Its value as a flux is that it possesses the property of dissolving any foreign matter present in the shape of sand, slag, or oxide, while it has practically no action on the crucible; therefore, any desired quantity can be used. It melts readily and forms a thin slag. Mix about 5 pounds of plaster of Paris with the washings when they are placed in the crucible; then melt in the usual manner. If the slag at the conclusion

of the melt is not sufficiently fluid, more should be added. When the metal is completely melted pour the entire contents of the crucible into ingot molds. Do not attempt to skim it. The slag will run into the molds with the metal and rise to the top. Allow the mass to cool and then dump the ingot molds.

Plaster of Paris is calcium sulphate; when used as a flux, the cotton seems to be one of simple solution: The molten plaster dissolves the foreign matter as sugar is dissolved by water. When coal is present in washings, as it usually is, there is a slight reduction of the sulphate to sulphide and there will be an odor of sulphur during the melting. This does no harm, in fact, it appears to act as if any iron be present, it is changed to sulphide and enters the slag.

**Aluminum.**—For years those who melted aluminum used no fluxes at all, not even charcoal, as it was found that this material did more harm than good. On account of the lightness of aluminum, charcoal does not readily free itself and is apt to become entangled in the metal and produce small, black spots in the casting. Within the past few years fluxes have come into use; the one most extensively used, and which has proved to be valuable is chloride of zinc. It seems to react with the aluminum, forming chloride of aluminum and metallic zinc, which alloys with the aluminum. When this takes place the dross is changed to a fine, granular condition and is readily skimmed off. When aluminum is melted the surface is covered with a rather thick mass; but the chloride of aluminum will change it to a perfectly clear one closely resembling in appearance molten tin or lead. The method of using chloride of zinc as a flux in melting aluminum is simple. Small pieces are thrown on the surface after the melting has been completed. Enough has been added when the surface is clear. A very small amount usually suffices, and for 50 pounds of aluminum a piece the size of a walnut is generally enough. The metal is stirred immediately after the addition and then skimmed.

## ALUMINUM ALLOYS

The following notes are from a paper prepared by Dr. J. W. Richards, for the Am. Soc. for Testing Materials, 1903.

Pure aluminum is a comparatively soft and weak metal; it hardens quickly while being worked, becomes harder, denser, more elastic and stronger, but goes to pieces if worked too far. To produce a thin sheet or fine wire it is necessary to anneal frequently, to remove the strains caused by the work. Castings of aluminum, unworked, are soft and weak.

The following table gives the usual limits of physical properties of No. 1 commercial aluminum, which averages 99 to 99.5% pure:

| | Elastic Limit (Pounds per Square Inch) | Ultimate Tensile Strength. (Pounds per Square Inch) | Percentage Reduction of Area |
|---|---|---|---|
| Castings | 8,500 | 14,000 to 18,000 | 15 |
| Sheet | 12,500 to 25,000 | 24,000 to 40,000 | 20 to 30 |
| Wire | 16,000 to 33,000 | 25,000 to 55,000 | 40 to 60 |
| Bars | 14,000 to 23,000 | 28,000 to 40,000 | 30 to 40 |

For all purposes where it is sufficiently hard and strong, it is advisable to use the pure metal, since it resists alteration by the atmosphere and other corroding agencies better than almost any of its alloys. For cast articles, wire, rods, or sheets, not sufficiently strong or hard when made of the pure metal, aluminum can be alloyed with small quantities of other metals, without materially increasing its specific gravity. The principal metals used for alloys are zinc, copper, nickel, magnesium, titanium, tungsten, chromium and manganese.

**Alloying.**—The aluminum used should be of No. 1 quality, which averages 99.5% aluminum. The commercial qualities of other metals are frequently so impure that they give alloys of quite different properties from the pure metals. This is particularly

true of zinc which often contains 1% or more of lead and considerable iron. As a general rule, it is advisable to melt the aluminum first, and then to stir or dissolve the other metal into it. Most metals, particularly copper, unite with aluminum with considerable energy, and dissolve quickly in it, even though the melting point be considerably higher. To facilitate the solution of a metal of very high melting point, such as nickel, it is advisable to prepare first an alloy of the metal with aluminum in somewhat like equal proportions. This alloy, cast into bars, is then added to the melted aluminum, and dissolves much faster and more uniformly than the pure metal.

Aluminum alloys, like aluminum, have large specific heats, and it takes a large amount of heat, though not a high temperature, to melt them. The characteristic of the furnace operation is therefore to have only a moderately hot fire, and it is of the greatest importance that the alloy be never over a cherry-red heat. The stirring rod may be a wrought-iron bar, if the temperature is kept low. If the temperature is high the iron bar will be corroded and the alloy injured; it is better to use a carbon rod for a stirrer, fastened into the end of an iron pipe for a handle.

**Melting Point.**—The addition of a few per cent of any metal to aluminum lowers the melting point. Adding copper, the melting point decreases until 33% of copper is present, above which it rises. Antimony is the most striking exception, small quantities increase the melting point very considerably.

**Specific Gravity.**—The alloys with magnesium, 2 to 12%, are the only ones which are lighter than aluminum itself; but they are lighter than their composition and the specific gravity of magnesium (1.72) would lead us to expect. Thus, 10% of magnesium would theoretically make a physical mixture with a specific gravity 0.16 less than aluminum, whereas it really gives an alloy 0.24 lighter. This points to expansion taking place during alloying. In the case of the other metals heavier than aluminum, their specific gravity is usually higher than would be calculated from the composition, pointing to a condensation or contraction taking place in alloying.

**Working and Annealing.**—All alloys are hardened by working and must be frequently annealed to avoid cracks. Working raises the tensile strength but decreases ductility and frequent annealing is necessary.

The annealing is done in a muffle, if possible, as it is advisable not to subject these alloys, especially magnalium, to the direct action of the flame, since absorption of gas and internal oxidation, or burning, takes place at redness without melting. Slabs and bars are heated to full dark red. Sheets must not be heated so high; a thin sheet is merely warmed to about 400° C. (752° F.) and then cooled in water. Very thin sheets can be put into hot oil and thus allowed to cool slowly.

**Chromium.**—Chromium hardens aluminum strongly, the alloys having somewhat of the qualities of self-hardening steel, i.e., retaining their hardness on heating or after annealing much better than any other of the aluminum alloys. Two to 3% of chromium is recommended as making the metal much harder but decreasing malleability considerably. Eleven per cent makes the alloy brittle, crystalline and unworkable.

**Titanium.**—Alloys up to 7% of titanium have been made, but the best is that with 2%. This has elasticity comparable to spring brass, and a tensile strength of 30,000 to 35,000 pounds when rolled hard with 3% elongation, and 21,000 pounds when annealed with 16.5% elongation. These alloys are difficult to make, as pure titanium is rare, and the only practicable method of manufacture is to dissolve titanic oxide in melted cryolite and add aluminum, which latter reduces the oxide and forms an alloy with the metal.

**Manganese.**—The addition of manganese to commercial aluminum up to 5% produces hard and rigid alloys. They can be made either by making a rich alloy of manganese and aluminum in the electric furnace, or diluting this down with pure aluminum. The addition of rich ferro-manganese to aluminum also serves to produce the alloys, but it has the disadvantage of introducing some iron and carbon into the alloy at the same time. Used with copper and nickel manganese makes the hardest light alloy of aluminum yet produced.

**Tin.**—The alloy of aluminum with 10% of tin is whiter than aluminum, its density is 2.85, its coefficient of expansion by heat is less than that of aluminum and it can be more easily soldered than pure aluminum. The tensile strength of a casting of

this alloy showed only 14,000 pounds per square inch, with 4% elongation, so that it is no stronger than pure aluminum and not as ductile.

**Nickel.**—Alloys of aluminum with nickel alone have not been found advantageous. An alloy with 4.5% nickel, had a coarsely crystalline fracture, rolled and worked well, but had poor mechanical properties. The commercial alloys which go under the name of nickel aluminum alloy are in reality ternary alloys of aluminum with nickel and copper. What are called nickel-aluminum casting alloys contain 7 to 10% of nickel and copper together, have an elastic limit of 8,500 to 12,000 pounds, ultimate strength of 15,000 to 20,000 pounds, with reduction of area of 6 to 8%.

**Tungsten.**—The precise effects of tungsten alone have not been very satisfactorily determined, since it is used in small amounts in conjunction with other hardeners of aluminum, such as with copper and iron, or copper and manganese, etc.

**Copper.**—Copper is one of the most frequently used hardening agents for aluminum, being often used alone and often associated with zinc, nickel and other metals. In casting, these copper alloys are only slightly stronger than pure aluminum, because of the segregation of the alloy, which takes place during slow cooling. It is only in chill castings that satisfactory results can be obtained. Slabs and bars for rolling or drawing should be cast in chill molds.

**Zinc.**—Zinc is the cheapest and at the same time one of the most efficient of the metals which improve the mechanical properties of aluminum. Proportions up to 33% are used; the alloys are malleable up to 15% and above that are still useful for making castings. Only the purest aluminum should be used, to get the best alloys. Casting in chills gives much better results than casting in sand; in the latter case the slow cooling seems to cause a separation.

The alloy with 15% zinc can be rolled and drawn. In chill castings it has an elastic limit of 16,000 pounds per square inch, a tensile strength of 22,330 pounds, an elongation of 6% in 2 inches and reduction of area of 10.50 per cent.

The alloy with 25% zinc has a tensile strength of 22,000 pounds, extension 1% and reduction of area 3%, when cast in sand. When cast in chill molds its tensile strength is 35,000 to 45,000 pounds, extension 1%, with a close fracture like high carbon steel. Its specific gravity is 3.4, which shows a contraction of 14% in the bulk of the constituents while alloying, and since one part of zinc has only one-eighth the volume of three parts of aluminum, the remarkable conclusion follows that the aluminum takes up one-third of its weight of zinc and actually decreases in volume some 2% in doing it. This probably accounts for the close grain and good working qualities of this alloy. It is non-magnetic, has a fine color, takes a high polish, and bids fair to be the most generally useful of all the light aluminum alloys.

Zinc alloys are the cheapest to make, and are equal in mechanical properties to very nearly the best alloys made with more expensive metals, and therefore promise to have, of all the light aluminum alloys, the largest sphere of usefulness.

## AMALGAMS

This term is applied to that class of alloys in which one of the combining metals is mercury. On adding successive small quantities of silver to mercury, a great variety of fluid amalgams are apparently produced; in reality, the chief, if not the sole, compound is a solid amalgam, which is merely diffused throughout the fluid mass. The fluidity of any amalgam would thus seem to depend on there being an excess of mercury above that necessary to form a definite compound. Some amalgams are solid, others liquid. They are, generally speaking, weak compounds, many of them being decomposed by pressure, and all are decomposed at a white heat. The principal amalgams are those of lead, zinc, tin, bismuth, cadmium, copper, silver, gold, sodium.

**Lead-Amalgam.**—This alloy may be formed by pouring molten lead into mercury; it has a higher specific gravity than either mercury or lead, as it undergoes contraction in combining. The color is a brilliant white. It remains liquid with as much as 33.0% lead, but when made of equal parts it crystallizes into a brittle solid.

**Zinc-Amalgam.**—Mercury combines readily with molten zinc; an amalgam of 8 parts of zinc to 1 part of mercury is very brittle. Singer recommends an amalgam

for rubbers of electric machines: 2 parts zinc, 1 part tin, and 4 to 6 parts mercury. Zinc plates, used in galvanic batteries, are generally coated with mercury by first cleaning the zinc plate in dilute sulphuric acid, and then rubbing in the mercury with a brush or rag.

**Tin-Amalgam.**—This is made by adding mercury to molten tin. If of 10 parts mercury and 1 part tin the amalgam is liquid, but equal parts of these metals make a brittle solid of tin-white color. By adding more mercury the amalgam becomes plastic; it may then be molded or pressed into shape, which will harden in a few days. A preparation of tin-amalgam has been used in dental work for filling teeth; it hardens with little or no expansion.

**Bismuth-Amalgam.**—Mercury will dissolve bismuth without losing its liquid form; an amalgam of 4 parts mercury and 1 part bismuth has been used as an occasional substitute for tin in tinning. With the addition of lead and tin it is occasionally used for silvering glass.

**Cadmium-Amalgam.**—Mercury combines readily with molten cadmium. The mercury is completely saturated in the proportions of 78.26% mercury; 21.74% cadmium. This is a tin-white brittle amalgam which softens when moderately heated; it has been used in dental work.

**Copper-Amalgam.**—Copper does not readily combine with mercury, but the amalgam may be formed by rubbing copper, which has been precipitated from its solution by zinc, first with a mercuric nitrate solution, then with mercury in a mortar. This amalgam is plastic when newly made, but becomes hard in a day or two; it may be softened by immersing it in boiling water or by simply pounding it. It hardens without expanding or contracting.

**Gold-Amalgam.**—Mercury has been extensively used in separating gold from crushed quartz rock in which the particles of gold are embedded. The mercury attaches the gold particles to itself forming a semi-fluid mass which needs only to be placed in a retort, applying heat and driving off the mercury, the gold remaining in the retort. The saturation point of gold and mercury is 2 parts gold for 1 part mercury, forming an amalgam of waxy consistence. Gold-amalgam dissolved in mercury becomes fluid, and when this solution is strained through chamois leather, mercury passes through, together with a small quantity of gold, and there remains a white amalgam of pasty consistence.

**Silver-Amalgam.**—Silver and mercury form a definite chemical compound, corresponding to the formula $Ag_2Hg_2$. By squeezing the excess of mercury through chamois leather an amalgam containing 43.7 parts of silver to 100 parts of mercury is obtained. Silver-amalgam can be prepared by adding mercury to a solution of silver nitrate; the amalgam is precipitated in a crystalline form called a silver tree, or *arbor Dianæ.*

**Sodium-Amalgam.**—Sodium combines rapidly with mercury at ordinary temperatures, the combination being attended with vivid combustion. This amalgam is used in the preparation of other amalgams. Metallic chlorides, such as those of silver and gold, for example, are decomposed by sodium-amalgam, and the reduced metal then unites with the mercury.

# INGOT COPPER

## NAVY DEPARTMENT

1. **Quality.**—Ingot copper to be refined new copper suitable for casting purposes:

Grade 1, to show on analysis 99.88 per cent of pure copper.

Grade 2, to show on analysis 99.25 per cent of pure copper.

2. **Form and Marking.**—To be furnished in standard commercial shaped ingots, between 9 inches and 12 inches in length, with brand name stamped or cast in.

3. **Purposes for Which Used.**—Grade 2 may be used in compositions of commercial brass (B-c), cast naval brass (N-c), screw pipe fittings (S-E), and commercial rolled brass (B-r).

Grade 1 should be used for other compositions of non-ferrous materials.

## COPPER SHEETS, PLATES, RODS, BARS, AND SHAPES, OR NON-FERROUS METAL Cu-r

NAVY DEPARTMENT

1. **General Instructions.**—General Instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Scrap.**—Scrap will not be used in the manufacture, except such as may accumulate in the manufacturers' plants from material of the same composition of their own make.

3. **Chemical and Physical Properties.**—The chemical and physical requirements shall be as follows:

| Letter | Name | Copper | Tin | Zinc | Lead Maximum | Iron Maximum | Ultimate Tensile Strength, Pounds per Square Inch | Yield Point, Pounds per Square Inch | Elongation in 2 Inches per Cent |
|---|---|---|---|---|---|---|---|---|---|
| Cu-r.. | Copper (rolled or drawn) | 99.5 (min.) | ... | ... | ... | ... | 30,000 | ....... | 25 |

4. **Test Pieces.**—Test pieces will be as nearly as possible of the same diameter as the rounds, or else they are not to be less than ½ inch diameter and taken at a distance from the circumference equal to one-half the radius of the rounds.

5. **Additional Tests.**—All bars to be clean and straight, of uniform color, quality, and size. Bars must stand:

(a) Being hammered hot to a fine point.

(b) Being bent cold through an angle of 120° and to a radius equal to the diameter or thickness of the test bar.

(c) The bending test bar may be the full-size bar, or the standard bar of 1 inch width and ½ inch thickness. In the case of bending test pieces of rectangular section, the edges may be rounded off to a radius equal to one-fourth of the thickness.

6. **Surface Inspection.**—Material must be free from all injurious defects, clean, smooth, must lie flat, and be within the gauge and weight tolerances.

7. **Trimming.**—Plates and sheets will be cut to the required dimensions and will be ordered in as narrow widths as can be used.

(a) The following will be considered stock lengths for copper sheets when ordered in 10-foot lengths:

40 per cent in weight may be in 8 to 10-foot lengths.
30 per cent in weight may be in 6- to 8-foot lengths.
20 per cent in weight may be in 4- to 6-foot lengths.
10 per cent in weight may be in 2- to 4-foot lengths.

No lengths less than 2 feet will be accepted and the total weight of all pieces on lengths less than 10 feet must not exceed 40 per cent in any one shipment.

(b) Rods and bars, when ordered to any length, will be received in stock lengths, unless it is specifically stated that the lengths are to be exact. Stock lengths will be as follows:

When ordered in 12-foot lengths, no lengths less than 8 feet.
When ordered in 10-foot lengths, no lengths less than 6 feet.
When ordered in 8-foot lengths, no lengths less than 6 feet.
When ordered in 6-foot lengths, no lengths less than 4 feet.

When ordered to the lengths given above, the weight of lengths less than length ordered shall not exceed 40 per cent of any one shipment.

This applies to all rods from ¼ to 1 inch diameter or thickness, whether round, rectangular, square, or hexagonal. Above 1 inch to and including 2 inches the lengths

will be random lengths from 4 to 10 feet. Above 2 inches the lengths are special, but no length will be less than 4 feet.

8. **Tolerances.**—No excess weight will be paid for, and no single piece that weighs more than 5 per cent above the calculated weight will be accepted.

UNDER WEIGHT AND GRADE TOLERANCES

| | Width of Sheets or Plates | | |
|---|---|---|---|
| | Up to 48 Inches, Inclusive | 48 to 60 Inches, Inclusive | Over 60 Inches |
| Tolerance...................... | 5 per cent. | 7 per cent. | 8 per cent. |

Material shall not vary throughout its length or width more than the given tolerance.

9. **Fracture.**—The color of the fracture section of test pieces and the grain of the material must be uniform throughout.

10. **Purposes for Which Used.**—The material is suitable for the following purposes: Copper pipe and tubing.

## SHEET COPPER FOR SHEATHING BOTTOMS OF WOODEN CRAFT

### NAVY DEPARTMENT

1. To be hard or soft rolled, as specified in the order; to be best commercial quality, in sheets 48 by 14 inches, smooth on both sides, free from all defects, blisters, bad edges and corners, and to contain at least 99 per cent pure copper. Sheets to be commercially flat and reasonably free from waves and buckles.

2. A variation of 7 per cent under gauge at edge of sheet, and a variation in weight of 5 per cent over or under will be allowed.

3. In ordering copper the thickness in decimals of an inch should be given, as shown in the first column of table below:

| Thickness | Ounces, per Square Foot | Weight of Sheet, 14 by 48 Inches | | Maximum Weight | | Minimum Weight | | Minimum Gauge |
|---|---|---|---|---|---|---|---|---|
| *Inches* | | *Lbs.* | *Oz.* | *Lbs.* | *Oz.* | *Lbs.* | *Oz.* | |
| 0.0189 | 14 | 4 | 1 | 4 | 4 | 3 | 14 | 0.0176 |
| .0203 | 15 | 4 | 6 | 4 | 10 | 4 | 2 | .0189 |
| .0216 | 16 | 4 | 10½ | 4 | 14 | 4 | 7 | .0201 |
| .0230 | 17 | 4 | 15½ | 5 | 4 | 4 | 11 | .0214 |
| .0243 | 18 | 5 | 4 | 5 | 8 | 5 | 0 | .0226 |
| .0257 | 19 | 5 | 8½ | 5 | 13 | 5 | 4 | .0239 |
| .0270 | 20 | 5 | 13½ | 6 | 2 | 5 | 9 | .0251 |
| .0297 | 22 | 6 | 6½ | 6 | 12 | 6 | 1 | .0277 |
| .0323 | 24 | 7 | 0 | 7 | 6 | 6 | 10 | .0301 |
| .0352 | 26 | 7 | 9 | 7 | 15 | 7 | 3 | .0328 |
| .0379 | 28 | 8 | 2½ | 8 | 9 | 7 | 12 | .0353 |
| .0406 | 30 | 8 | 12 | 9 | 3 | 8 | 5 | .0378 |
| .0433 | 32 | 9 | 5 | 9 | 13 | 8 | 13 | .0404 |

4. Each sheet to have thickness in decimals of an inch, or weight in ounces per square foot, stamped or stenciled clearly and permanently in large letters on one corner—for example, 28 ounces. The weight stamped or stenciled on the sheet will be the same as

the order calls for, although, on account of the weight tolerance, the sheet may be actually nearer the next gauge. Net weight only will be paid for.

## REFINED COPPER FOR USE IN MAKING CARTRIDGE CASES

NAVY DEPARTMENT

1. **Material.**—High-grade lake copper, to be refined from ore of the best quality.
2. **Analysis.**—Chemical analysis shall show 99.90 per cent pure copper, with not more than 0.0025 per cent of sulphur or arsenic, and only traces of other impurities.
3. **Size of Ingots.**—To be furnished in ingots between 9 and 12 inches long.
4. **Branding.**—The brand of copper shall be cast in the ingot.
5. **General.**—Electrolytic copper will not be accepted under these specifications. Bidders are required to specify brand of copper offered.

## SILICON COPPER OR COMPOSITION Cu-si

NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.
2. **Scrap.**—Scrap will not be used, except such as may result from the process of manufacture of articles of similar composition.
3. **Chemical Properties.**—The chemical requirements shall be as follows:

| Copper | Tin | Zinc | Iron | Lead | Silicon, Minimum |
|---|---|---|---|---|---|
| *Per Cent* Remainder | .......... | .......... | .......... | .......... | *Per Cent* 10 |

Material to be 99.5 per cent pure. Analysis is to be made from every lot of 300 pounds or less.

4. **Workmanship.**—Material must be in accordance with detail specifications and free from all injurious defects.
5. **Fracture.**—The color of the fracture section of test pieces and the grain of the metal must be uniform throughout.
6. **Marking.**—Each ingot will be plainly stamped with the percentage of silicon and copper, as determined by analysis.

## PHOSPHOR COPPER OR COMPOSITION Cu-p

NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.
2. **Scrap.**—Scrap will not be used, except such as may result from the process of manufacture of articles of similar composition.
3. **Chemical Properties.**—Chemical requirements shall be as follows:

| Copper | Tin | Zinc | Iron | Lead | Phosphorus, Minimum |
|---|---|---|---|---|---|
| *Per Cent* Remainder | *Per Cent* .......... | *Per Cent* .......... | *Per Cent* .......... | *Per Cent* .......... | *Per Cent* 10 |

Material to be 99.5 per cent pure. Analysis to be made from every lot of 300 pounds or less.

4. **Workmanship.**—Material must be in accordance with detail specifications and free from all injurious defects.

5. **Fracture.**—The color of the fracture section of test pieces and the grain of the metal must be uniform throughout.

6. **Marking.**—Each ingot will be plainly stamped with the percentage of phosphorus and copper, as determined by analysis.

## INGOT TIN

### NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form a part of these specifications.

2. **Delivery.**—To be delivered f.o.b. cars at navy yard indicated.

3. **Quality.**—To be prime quality tin, and to contain not less than 99.75 per cent pure tin, nor more than 0.1 per cent of either of the following metals: Lead, antimony, arsenic, copper; nor more than 0.01 per cent of sulphur; the total amount of impurities allowed being 0.25 per cent. To be new metal, free from scrap or remelted metal, and in commercial and branded ingots.

4. **Size of Order and Ingots.**—Unless smaller quantities are actually necessary, requisitions shall call for quantities amounting to 11,200 pounds (5 gross tons) or multiples thereof. No particular size of ingot to be specified.

5. **Place of Inspection.**—Inspection to be made at steamer's dock or in warehouse, if practicable to the bureau concerned; each bidder to state in his proposal the name and location of the dock or warehouse where inspection is to be made.

6. **Brand.**—The inspector shall note that the tin is branded before samples are taken and shipment authorized to the yard concerned.

7. **Lots to be Analyzed.**—For each lot of 11,200 pounds a sample of equal amount will be taken from each of four ingots, the four samples so taken to be blended and analysis made from a sample of this blend.

8. **Rejection.**—If, upon delivery, the tin is found not to be the tin submitted for inspection, or if it does not contain the percentage of pure tin specified, or if it contains an excess of lead or other impurities, the delivery will be rejected.

## PHOSPHOR TIN

### NAVY DEPARTMENT

1. Phosphor tin to be furnished in the form of ingots of uniform quality and fracture throughout; to be made of new material of the best grade; of domestic manufacture; to be at least 99.5 per cent pure, to be of the following composition:

Phosphorus, not less than 5 per cent.

Tin, the remainder.

2. Each ingot to be plainly stamped with the percentage of phosphorus and tin, as determined by analysis. Analysis to be made from every lot of 300 pounds or less.

## SLAB ZINC

### NAVY DEPARTMENT

1. **General Instructions.**—General instructions and specifications issued by the bureau concerned shall form a part of these specifications.

2. **Quality.**—Under these specifications virgin spelter—that is, spelter made from ore or similar raw material by a process of reduction and distillation and not produced from reworked metal—is required.

3. **Marks.**—A brand shall be cast in each slab by which the maker and grade can be identified.

4. **Lots.**—The maker shall use care to have each lot as uniform quality as possible.

5. **Chemical Requirements.**

| Grade | Zinc | Lead Maximum | Iron Maximum | Sulphur | Arsenic | Antimony |
|---|---|---|---|---|---|---|
| | | *Per Ct.* | *Per Ct.* | *Per Ct.* | *Per Ct.* | *Per Ct.* |
| A............. | Remainder....... | 0.50 | 0.04 | 0 | 0 | 0 |
| B............. | Do | 1.5 | .08 | (1) | (1) | (1) |

[1] Practically free.

Grade A shall be free from aluminum.

6. **Physical Requirements.**—The slab shall be reasonably free from surface corrosion or adhering foreign matter.

7. **Purpose.**—Grade A shall be required for special foundry work for composition material where lead allowance is low. Grade B shall be required for galvanizing and general foundry work which permits a large amount of lead in the slab zinc used.

**Note for General Storekeepers.**—Grade A should only be called for when Grade B will not be satisfactory.

## ROLLED ZINC PLATES OR COMPOSITION Zn-r

### NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Size and Weight.**—Plates will be of thicknesses and dimensions as specified and net weight only will be paid for. The standard sizes of sheets for various thicknesses, also the external sizes possible for the various thicknesses, are given below:

### .HULL ZINCS

Standard size 12 inches by 6 inches by ½ inch.

Other sizes of zincs for circular openings, etc., are given in the table below:

| Thickness | Standard Size | Extreme Size | Thickness | Standard Size | Extreme Size |
|---|---|---|---|---|---|
| *Inch* | *Inches* | *Inches* | *Inch* | *Inches* | *Inches* |
| ⅛ (0.125) | 36 by 84 | 60 by 96 | ⅝ ( .625) | 24 by 48 | 24 by 48 |
| ¼ ( .250) | 36 by 84 | 36 by 84 | ¾ ( .750) | 24 by 36 | 24 by 48 |
| ⅜ ( .375) | 24 by 48 | 24 by 72 | ⅞ ( .875) | 24 by 36 | 24 by 36 |
| ½ ( .500) | 24 by 48 | 24 by 72 | 1 (1.000) | 24 by 36 | 24 by 36 |

### ZINCS FOR BOILERS, SALT-WATER PIPING, ETC.

Standard size, 12 inches by 6 inches by ½ inch, with one central hole ¾ inch in diameter.

3. **Tolerance.**—A tolerance of 10 per cent over or under weight will be permitted, the weight of 1 cubic inch of rolled sheet zinc being 0.2605 pound. The tolerance for under gauge at edge of sheet is 15 per cent on a sheet 3 feet wide; other widths proportional.

4. **Material.**—The plates must be made of zinc, containing not less than 98.5 per cent pure zinc, nor more than 0.08 per cent of iron, and must be thoroughly compressed by rolling to make a solid homogeneous slab, with a surface smooth and free from all defects.

5. **Test.**—The plates must be able to stand bending through an angle of 45° over a round surface whose diameter is 1 inch without break or cracks, at a temperature not exceeding 100° F.

6. **Packing.**—To be delivered in boxes of about 250 pounds each; boxes to be well made of 1-inch pine or spruce, securely strapped with iron.

7. **Marking.**—Net weight and number of plates to be marked on each box.

## PIG LEAD

### NAVY DEPARTMENT

1. **Grade.**—Pig lead will be required for either as No. 1 or No. 2. No. 1 grade is for foundry use for alloys and compositions, and No. 2 is for weights, ballast, etc.

2. **No. 1 Pig Lead; Analysis 99.9 per Cent.**—No. 1 pig lead to be good lead of any well-known brand, and must show on analysis not less than 99.9 per cent of metallic lead (Pb.); to be product of new ore.

3. **No. 2 Pig Lead.**—No. 2 pig lead to be either old or new lead.

4. **Weight of Pigs.**—Pig lead will be delivered in pigs weighing about 80 to 90 pounds, unless otherwise specified.

5. **Test.**—From each 2 tons in a delivery of No. 1 pig lead one pig will be selected, and an equal amount of clean fine drillings will be taken from each sample pig and thoroughly mixed. The sample for analysis will be taken from this mixture.

## INGOT ALUMINUM

### NAVY DEPARTMENT

1. Aluminum ingots shall contain not less than 99 per cent of aluminum.

2. A chemical analysis shall be made upon each lot of 2,000 pounds or each fraction thereof, except as otherwise noted. For shipments in carload lots of 30,000 pounds or more, not more than five (5) analyses shall be required for each carload shipment.

3. The tensile strength of the aluminum shall not be less than 12,000 pounds per square inch when cast in a test bar of dimensions outlined below. The test bar shall be cast in a thoroughly workmanlike manner. The quality shall be judged from the average result obtained from at least six (6) bars.

Dimensions of Bar

| | Inches |
|---|---|
| Diameter of body | 0.5 |
| Length of body | 2.0 |
| Length of fillets | .125 |
| Diameter of grips | .6 |
| Length of grips | 4.25 |

4. Elongation between 2-inch lengths on a bar of the dimensions given in paragraph 3 shall not be less than 20 per cent. The bar may be the same one used for tensile strength determination.

5. In case the chemical analysis shows an aluminum content less than 99 per cent, the shipment shall be resampled and reanalyzed. If the second analysis, or analyses, as the case may be, also show an aluminum content below 99 per cent, the entire lot represented by the analyses will be rejected.

6. In case the tensile strength and elongation fall below the requirements as described in paragraphs 3 and 4, the lot or shipment shall be resampled and retested. In case the second test fails to meet the requirements, the lot or shipment will be rejected.

## GUN METAL, CAST, OR COMPOSITION G

### NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Scrap.**—Scrap will not be used, except such as may result from the process of manufacture of articles of similar composition.

3. **Chemical and Physical Properties.**—The physical and chemical requirements shall be as follows:

| Minimum Tensile Strength, Pounds per Square Inch | Minimum Yield Point, Pounds per Square Inch | Minimum of Elongation in 2 Inches | Copper | Tin | Zinc | Iron, Maximum | Lead, Maximum |
|---|---|---|---|---|---|---|---|
| | | *Per Ct.* | *Per Ct.* | *Per Ct.* | *Per Ct.* | *Per Ct.* | *Per Ct.* |
| 30,000 | 15,000 | 15 | 87–89 | 9–11 | 1–3 | 0.06 | 0.2 |

4. **Waiving of Physical Tests.**—Physical tests may be waived by the bureau concerned or by the inspector through whom request for inspection is made on small castings of which the factor of safety is large by reason of necessities of design.

5. **Workmanship.**—The castings must be made in accordance with the drawings and specifications—sound, clean, free from blow-holes, porous places, cracks, or any other defects which will materially affect their strength or appearance or which indicate an inferior quality of metal.

6. **Test Lots.**—Castings weighing less than 250 pounds, finished, may be tested by lots or heat, a lot not to exceed 250 pounds, and a heat not to exceed 500 pounds of finished castings. Each lot or heat will be represented by one test specimen when attached to a casting or when a casting is sacrificed to obtain a test specimen.

7. **Test Coupons.**—If the castings are too small for the attachment of coupons, the test pieces may be cast separately, from the same metal, under as nearly as possible the same conditions as the castings. Where test pieces are cast separately from the castings, two pieces will be required, one to be poured before and one after the castings. Coupons shall not be detached from castings until they are stamped by the inspector. If the test pieces are cast separately from the casting, they must be cast in the same flask with the casting and must be removed from it in the presence of the inspector and stamped by him at the time they are taken out of the molds.

8. **Fracture.**—The color of the fracture section of test pieces and the grain of the metal must be uniform throughout.

9. **Purposes for Which Used.**—The material is suitable for the following purposes: All composition valves 4 inches in diameter and above; expansion joints, flanged pipe fittings, gear wheels, bolts and nuts, miscellaneous brass castings, all parts where strength is required of brass castings or where subjected to salt water, and for all purposes where no other alloy is specified.

Composition Valves.—Safety and relief, feed check and stop, surface blow, drain, air, and water cocks, main stop, throttle, reducing, sea, safety, sluice, and manifolds at pumps.

Heads, shapes, and water chests for condensers, distillers, feed-water heaters, and oil coolers.

Pumps.—Air-pump casing, valve seats, buckets, main circulating, water cylinders, valve boxes, water pistons, stuffing boxes, followers, glands—in general, the water end of pumps complete except as specified.

Stuffing Boxes.—Glands, bushings for iron or steel boxes.

Blowers.—Bearing boxes.

Journal Boxes.—Distance pieces.

Miscellaneous.—Grease extractors; steam strainers, separators, casting for stern tube and propeller shafts, propeller hub caps.

Bearings.—Main, stern tube, strut, and spring.

Spring Bearings.—Glands and baffles.

## VALVE BRONZE OR COMPOSITION M

NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Scrap.**—Scrap will not be used, except such as may result from the process of manufacture of articles of similar composition.

3. **Chemical Properties.**—The chemical requirements shall be as follows:

| Copper, Minimum | Tin, Minimum | Zinc | Iron, Maximum | Lead, Maximum |
|---|---|---|---|---|
| *Per Cent* | *Per Cent* | *Per Cent* | *Per Cent* | *Per Cent* |
| 87 | 7 | Remainder | 0.06 | 1.0 |

4. **Workmanship.**—The castings must be made in accordance with the drawings and specifications—sound, clean, free from blow-holes, porous places, cracks, or any other defects which will materially affect their strength or appearance or which indicate an inferior quality of metal.

5. **Fracture.**—The color of the fracture section of test pieces and the grain of the metal must be uniform throughout.

6. **Supersedes.**—This specification supersedes Composition M in Specifications Part II, Steam Engineering (Revised July 1, 1910).

7. **Purposes for Which Used.**—The material is suitable for the following purposes: Valves below 4 inches for steam and general purposes for which the material is not otherwise specified, manifolds and cocks, relief valves, composition lug sockets, and pad eyes not requiring special strength, hose couplings, and fittings.

## JOURNAL BRONZE OR COMPOSITION H

NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Scrap.**—Scrap will not be used, except such as may result from the process of manufacture of articles of similar composition.

3. **Chemical Properties.**—The chemical requirements shall be as follows:

| Copper | Tin | Zinc | Iron, Maximum | Lead, Maximum | |
|---|---|---|---|---|---|
| *Per Cent* | *Per Cent* | *Per Cent* | *Per Cent* | *Per Cent* | |
| 82–84 | 12.5–14.5 | 2.5–4.5 | 0.06 | 1.0 | Normal 83–13½–3½ |

4. **Workmanship.**—Material must be in accordance with detail specifications and free from all injurious defects.

5. **Fracture.**—The color of the fracture section of test pieces and the grain of the metal must be uniform throughout.

6. **Supersedes.**—This specification supersedes Composition H in Specifications Part II, Steam Engineering (Revised July 1, 1910).

7. **Purposes for Which Used.**—The material is suitable for the following purposes: Bearings, journal boxes, bushings, and sleeves, slides, slippers, guide gibs, wedges on water-tight doors, and all parts subject to considerable wear, for reciprocating engines in valve stem cross-head bottom brass, link block gibs, amd suspension link brasses.

## TORPEDO BRONZE

### NAVY DEPARTMENT

1. **General.**—To be drawn or rolled bright and to be uniform in quality and color, to be free from cracks, flaws, blow-holes, seams, or other injurious imperfections; to have a workmanlike finish and be true to the sizes ordered.

2. **Physical Properties.**—Ultimate tensile strength, minimum, 60,000 pounds; yield point, minimum, 35,000 pounds; elongation in 2 inches, minimum, 30 per cent; contraction, 45 per cent.

3. **Chemical Properties.**—Copper, 59 to 62 per cent; tin, 0.5 to 1.5 per cent; lead, maximum, 0.3 per cent; iron, maximum, 0.1 per cent; and the remainder zinc. To contain no aluminum.

4. **Tests.**—Must stand hammering hot to a fine point and bending cold through 120° with inner radius equal to diameter or thickness of bar.

5. **Machining Qualities.**—To be adapted to free and easy cutting in screw machines; to give maximum results in drilling and turning; to take a perfect thread in die, threading machine, or lathe. Any not found up to the standard as regards free working qualities to be replaced at the expense of the contractor. To determine this factor, bidder may submit samples, prior to opening bids; the suitability of these samples, if submitted, will be determined prior to awarding contract. A portion of the contractor's samples will be retained until the material has been used up, to be used as a comparison piece in determining the relative machining qualities.

## MANGANESE BRONZE, CAST, OR COMPOSITION Mn-c

### NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Scrap.**—Scrap will not be used, except such as may result from the process of manufacture of articles of similar composition.

3. **Chemical and Physical Properties.**—The physical and chemical requirements shall be as follows:

| Minimum Tensile Strength, Pounds per Square Inch | Minimum Yield Point, Pounds per Square Inch | Minimum of Elongation in 2 Inches | Copper | Tin, Maximum | Zinc | Iron, Maximum | Lead, Maximum | Aluminum, Maximum | Manganese, Maximum |
|---|---|---|---|---|---|---|---|---|---|
| | | *Per Cent* | *Per Cent* | *Per Cent* | *Per Cent* | *Per Cent* | *Per Cent* | *Per Cent* | *Per Cent* |
| 65,000 | 30,000 | 20 | 56–58 | 1 | 40–42 | 1 | 0.2 | 0.5 | 0.3 |

4. **Test.**—The castings will be required to stand a practical foundry test under the supervision of a foreman experienced in making manganese-bronze castings.

5. **Waiving of Physical Tests.**—Physical tests may be waived by the bureau concerned or by the inspector through whom request for inspection is made on small castings of which the factor of safety is large by reason of necessities of design.

6. **Workmanship.**—The castings must be made in accordance with the drawings and specifications—sound, clean, free from blow-holes, porous places, cracks, or any other defects which will materially affect their strength or appearance or which indicate an inferior quality of metal.

7. **Test Lots.**—Castings weighing less than 250 pounds, finished, may be tested by lots or heat, a lot not to exceed 250 pounds, and a heat not to exceed 500 pounds of finished castings. Each lot or heat will be represented by one test specimen when attached to a casting or when a casting is sacrificed to obtain a test specimen.

8. **Test Coupons on Castings.**—Coupons shall not be detached from castings until they are stamped by the inspector. If the test pieces are cast separately from the casting, they must be cast in the same flask with the casting and must be removed from it in the presence of the inspector and stamped by him at the time they are taken out of the moulds. If the castings are too small for the attachment of coupons, the test pieces may be cast separately from the same metal, under as nearly as possible the same conditions as the casting. Where test pieces are cast separately from the castings, two pieces will be required, one to be poured before and one after the castings.

**Tests on Ingots.**—Where individual tests are made, test pieces may be taken from any portion of an ingot. Two specimens, taken from the same portion of the same ingot, both falling below specification requirements, or any single specimen falling more than 5 per cent below specification requirements, shall cause the rejection of that heat.

9. **Forging Test.**—A piece forged into a bar must stand hammering hot to a fine point.

10. **Bending Test.**—A similar piece must stand bending through an angle of 120° and to a radius equal to the thickness of the bar.

11. **Fracture.**—The color of the fracture section of test pieces and the grain of the metal must be uniform throughout.

12. **Purposes for Which Used.**—The material is suitable for the following purposes: Propeller hubs, propeller blades, engine framing, castings requiring great strength, such as main gearing in steering engine; worm-wheels in windlass or turning gear for turrets.

13. This specification supersedes Composition Mn-c in Specifications Part II, Steam Engineering (Revised July 1, 1910).

NOTE.—**Proprietary Bronzes.**—Proprietary bronzes differing from the above will be accepted, provided such differences are clearly noted and described by the bidder, and provided further that the bronze offered under these conditions is found to meet fully the physical tests and fulfil equally well the specific requirements of the Government. No metal containing above 1 per cent of lead will be accepted.

# PHOSPHOR BRONZE, CAST, OR COMPOSITION P-c

## NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Scrap.**—Scrap will not be used, except such as may result from the process of manufacture of articles of similar composition.

3. **Physical and Chemical Properties.**—The physical and chemical requirements shall be as follows:

| Grade | Minimum Tensile Strength, Pounds per Square Inch | Minimum Yield Point, Pounds per Square Inch | Minimum of Elongation in 2 Inches | Copper | Tin | Zinc | Iron, Maximum | Lead, Maximim | Phosphorus, Maximum |
|---|---|---|---|---|---|---|---|---|---|
| | | | *Per Cent* | *P. Ct.* | *P. Ct.* | *Per Cent* | *P. Ct.* | *P. Ct.* | *Per Ct.* |
| 1 | 50,000 | 25,000 | 25 | 85–90 | 6–11 | Remainder | 0.06 | 0.2 | 0.3 |
| 2 | 35,000 | 20,000 | 18 | 78–81 | 9–13 | | .... | 8–11 | 0.7–1 |

4. **Waiving of Physical Tests.**—Physical tests may be waived by the bureau concerned or by the inspector through whom request for inspection is made on small castings of which the factor of safety is large by reason of necessities of design.

5. **Workmanship.**—The castings must be made in accordance with the drawings and specifications—sound, clean, free from blow-holes, porous places, cracks, or any other defects which will materially affect their strength or appearance or which indicate an inferior quality of metal.

6. **Test Lots.**—Castings weighing less than 250 pounds, finished, may be tested

by lots or heat, a lot not to exceed 250 pounds, and a heat not to exceed 500 pounds of finished castings. Each lot or heat will be represented by one test specimen when attached to a casting or when a casting is sacrificed to obtain a test specimen.

7. **Test Coupons.**—If the castings are too small for the attachment of coupons, the test pieces may be cast separately from the same metal under as nearly as possible the same conditions as the castings. Where test pieces are cast separately from the castings, two pieces will be required, one to be poured before and one after the castings. Coupons shall not be detached from castings until they are stamped by the inspector. If the test pieces are cast separately from the casting, they must be cast in the same flask with the casting and must be removed from it in the presence of the inspector and stamped by him at the time they are taken out of the moulds.

8. **Fracture.**—The color of the fracture section of test pieces and the grain of the metal must be uniform throughout.

9. **Purposes for Which Used.**—The material is suitable for the following purposes:

Grade 1.—Valve stems and fittings, etc., exposed to the action of salt water; sheathing, gears, and driving or main nuts for steering gears; castings where strength and incorrodibility are required.

Grade 2.—Gun fittings (ordnance).

# PHOSPHOR BRONZE, ROLLED, OR DRAWN, OR COMPOSITION P-r

## NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Scrap.**—Scrap will not be used in the manufacture, except such as may accumulate in the manufacturers' plants from material of the same composition of their own make.

3. **Chemical and Physical Requirements.**—The chemical and physical requirements shall be as follows:

| Grade | Minimum Tensile Strength, Pounds per Square Inch | Minimum Yield Point, Pounds per Square Inch | Minimum of Elongation in 2 Inches | Copper | Tin | Zinc, Maximum | Iron, Maximum | Lead, Maximum | Phosphorus, Maximum |
|---|---|---|---|---|---|---|---|---|---|
| | | | *Per Cent* | *P. Ct.* | *P. Ct.* | *P. Ct.* | *P. Ct.* | *P. Ct.* | *P. Ct.* |
| 1 | 120,000 | (a) 90,000 | 25 | 94–96 | 5–4 | (d) | (d) | (d) | 0.10 |
| | 80,000 | (b) 60,000 | ........ | .... | .... | .... | .... | .... | ...... |
| | 60,000 | (c) 45,000 | ........ | .... | .... | .... | .... | .... | ...... |
| 2 | 50,000 | 25,000 | 25 | 85–95 | 10–5 | 4 | 0.06 | 0.2 | .15 |

(a) For diameters less than ⅛ inch.
(b) For diameters ⅛ inch to ½ inch, inclusive.
(c) For diameters over ½ inch.
(d) For total of these three impurities not to exceed 0.10 per cent.

4. **Additional Tests.**—All bars to be clean and straight, of uniform color, quality, and size. Bars must stand:

(a) Being hammered hot to a fine point.

(b) Being bent cold through an angle of 120° and to a radius equal to the diameter or thickness of the test bar.

The bending test bar may be the full-size bar, or the standard bar of 1 inch width and ½ inch thickness. In case of bending test pieces of rectangular section, the edges may be rounded off to a radius equal to one-fourth of the thickness.

5. **Surface Inspection.**—Material must be free from all injurious defects, clean, smooth, and must lie flat.

6. **Trimming.**—Plates and sheets will be cut to the required dimensions and will be ordered in as narrow widths as can be used.

(a) The following will be considered stock lengths for sheets when ordered in 10-foot lengths:

40 per cent in weight may be in 8- to 10-foot lengths.

30 per cent in weight may be in 6- to 8-foot lengths.

20 per cent in weight may be in 4- to 6-foot lengths.

10 per cent in weight may be in 2- to 4-foot lengths.

No lengths less than 2 feet will be accepted, and the total weight of all pieces on lengths less than 10 feet must not exceed 40 per cent in any one shipment.

(b) Rods and bars, when ordered to any length, will be received in stock lengths, unless it is specifically stated that the lengths are to be exact. Stock lengths will be as follows:

When ordered in 12-foot lengths, no lengths less than 8 feet.

When ordered in 10-foot lengths, no lengths less than 6 feet.

When ordered in 8-foot lengths, no lengths less than 6 feet.

When ordered in 6-foot lengths, no lengths less than 4 feet.

When ordered to the lengths given above, the weight of lengths less than length ordered shall not exceed 40 per cent of any one shipment.

This applies to all rods from $\frac{1}{4}$ to 1 inch diameter or thickness, whether round, rectangular, square, or hexagonal. Above 1 inch to and including 2 inches the lengths will be random lengths from 4 feet to 10 feet. Above 2 inches the lengths are special, but no length will be less than 4 feet.

7. **Fracture.**—The color of the fracture section of test pieces and the grain of the material must be uniform throughout.

8. **Purposes for Which Used.**—The material is suitable for the following purposes:

Grade 1.—For rods, pins, spring wire, etc.

Grade 2.—Pump rods, valve stems, objects exposed to salt water.

## VANADIUM BRONZE CASTINGS OR COMPOSITION Vn-c

### NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Physical Properties.**—The physical requirements shall be as follows:

Minimum tensile strength, 55,000 pounds per square inch.

Minimum yield point, 22,500 pounds per square inch.

Minimum elongation, 25 per cent in 2 inches.

3. **Chemical Requirements.**—The chemical requirements shall be as follows:

Minimum copper, 61 per cent.

Maximum zinc, 38 per cent.

Remainder not to exceed 1 per cent tin, with lead, bismuth, aluminum, vanadium, and nickel.

4. **Test Specimens.**—Standard turned test specimens, 2 inches gauge length, type No. 1, shall be used in determining physical properties, as specified above.

5. **Number and Location of Test Specimens.**—The test specimens shall be taken from the casting in sufficient number and so located as thoroughly to exhibit the character of the casting.

6. **Rejection After Delivery.**—The acceptance of any casting by the inspector will not release the makers thereof from the necessity of replacing the casting should it fail in proof test or trial, or in working, or exhibit any defect after delivery.

# ROLLED MEDIUM BRONZE PLATES UP TO 3/8-INCH THICK, SHAPES, RIVET ROUNDS, AND BARS

(For Structural and Forging Purposes)

NAVY DEPARTMENT

Medium bronze plates up to 3/8 inch in thickness, shapes, rivet rounds, and bars for structural purposes to be made from best quality materials of purest commercial quality. The copper must be lake copper or its equivalent. The material must be free from surface defects, and must be cleaned and straightened.

Tensile tests made in accordance with instructions below must show for rivet rounds, and for hexagonal and octagonal bars for machinery or forging purposes, an ultimate tensile strength of not less than 60,000 pounds per square inch, an elastic limit of not less than one-half the ultimate tensile strength, and an elongation in 2 inches of not less than 25 per cent.

Tensile tests must show for irregular shapes (material such as channels, angles, I beams, and other similar shapes) an ultimate tensile strength of not less than 56,000 pounds per square inch, an elastic limit of not less than 40 per cent of the ultimate tensile strength, and an elongation in 8 inches of not less than 25 per cent.

Tensile tests must show for plates up to and including 30 inches in width an ultimate tensile strength of not less than 56,000 pounds per square inch, and for plates having a width greater than 30 inches an ultimate tensile strength of not less than 54,000 pounds per square inch. Tensile tests of all plates must show an elastic limit of not less than one-half the ultimate tensile strength and an elongation of not less than 25 per cent in 8 inches. Test specimens to be cut lengthwise from plates and shall be machined only on cut edges.

A tolerance of 5 per cent over or below the calculated weight will be allowed, and any excess weight up to 5 per cent will be paid for. Larger excess weight, if accepted, will not be paid for. Various composition materials otherwise conforming to the specifications but manufactured under proprietary processes or having proprietary names will be accepted as coming under this head.

Requisitions should specify the thickness of plates in common fractions or decimals of inches. Shapes should be specified by width and thickness of flanges in inches, bars by shape and dimensions in inches, and rivet rounds by diameter in inches.

All handling of material necessary for purposes of inspection shall be done at the expense of the contractor, and all test specimens necessary for the determination of the qualities of material used shall be prepared and tested at the expense of the contractor.

Test specimens cut from plates must stand being hammered hot to a sharp edge, and being bent cold through an angle of 120° to a radius equal to the thickness of the plate.

Bars must stand being hammered hot to a point when heated to a cherry red and being bent cold through an angle of 120° and to a radius equal to the diameter or thickness of the bar. Shapes must stand being forged hot and a strip cut lengthwise must stand bending cold through an angle of 120° to a radius equal to the thickness of the strip. Rivet rounds or bars intended for bolts will be tested by heading in a bolt machine and upsetting the end by hammering under conditions simulating actual riveting. The material must show satisfactory working qualities. If the bars are intended for rivets, bolts, or other important parts subject to stress, one test piece for every lot of 400 pounds or less shall be taken; in the case of large lots of bars and for plates and shapes the number of test pieces to be left to the judgment of the inspector.

## TENSILE TESTS AND TEST PIECES

The tensile strength herein specified means the ultimate tensile strength per square inch of original cross-section. The elastic limit may be measured by the drop of the beam or the halt of the gauge of the testing machine. The elongation is that obtained after fracture. In the case of test pieces of rectangular section the reduction of area is

to be measured by the product of the average width and thickness of the reduced area and not the minimum width and thickness.

Each tensile-test piece shall be subjected to a direct tensile stress until it breaks, in a machine of standard manufacture, running at a pulling speed of not less than 1 inch and not more than 5 inches per minute for 8-inch test pieces.

Tensile-test pieces shall be uniform in cross-section between measuring points, and are to have a length of 8 inches or 2 inches, as required, between measuring points.

Full-size bars and rods within the capacity of the testing machine may be used as tensile-test pieces, and in this case the bending tests also may be taken from the full-size bars and rods.

The standard width of tensile-test pieces from plates will be 1½ inches, the thickness the same as the plate, and the length between measuring points 8 inches.

In the case of bending-test pieces of rectangular section the edges may be rounded off to a radius equal to one-fourth of the thickness.

For plates the width of the bending-test pieces shall be not less than 1½ inches and the thickness that of the plate. The bending may be done by either pressure or by blows.

## MONEL METAL, CAST, OR COMPOSITION Mo-c

### NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Scrap.**—Scrap will not be used, except such as may result from the process of manufacture of articles of similar composition.

3. **Chemical and Physical Properties.**—The physical and chemical requirements shall be as follows:

| Minimum Tensile Strength, Pounds per Sq. Inch | Minimum Yield Point, Pounds per Square Inch | Minimum of Elongation in 2 Inches | Copper | Tin | Zinc | Iron, Maximum | Lead, Maximum | Aluminum | Nickel, Minimum |
|---|---|---|---|---|---|---|---|---|---|
| | | *P. Ct.* | *P. Ct.* | *P.Ct.* | *P.Ct.* | *P.Ct.* | *P.Ct.* | *P.Ct.* | *P.Ct.* |
| 65,000 | 32,500 | 25 | Remainder | .... | .... | 6.5 | 0 | 0.5 | 60 |

4. **Waiving of Physical Tests.**—Physical tests may be waived by the bureau concerned or by the inspector through whom request for inspection is made on small castings of which the factor of safety is large by reason of necessities of design.

5. **Workmanship.**—The castings must be made in accordance with the drawings and specifications—sound, clean, free from blow-holes, porous places, cracks, or any other defects which will materially affect their strength or appearance or which indicate an inferior quality of metal.

6. **Test Lots.**—Castings weighing less than 250 pounds finished may be tested by lots or heat, a lot not to exceed 250 pounds, and a heat not to exceed 500 pounds of finished castings. Each lot or heat will be represented by one test specimen when attached to a casting or when a casting is sacrificed to obtain a test specimen.

7. **Test Coupons.**—If the castings are too small for the attachment of coupons, the test pieces may be cast separately, from the same metal, under as nearly as possible the same conditions as the casting. Where test pieces are cast separately from the castings, two pieces will be required, one to be poured before and one after the castings. Coupons shall not be detached from castings until they are stamped by the inspector. If the test pieces are cast separately from the casting, they must be cast in the same flask with the casting and must be removed from it in the presence of the inspector and stamped by him at the time they are taken out of the molds.

8. **Fracture.**—The color of the fracture section of test pieces and the grain of the metal must be uniform throughout.

9. **Supersedes.**—This specification supersedes Composition Mo-c in Specifications Part II, Steam Engineering (Revised July 1, 1910).

10. **Purposes for Which Used.**—The material is suitable for the following purposes: Valve fittings, plumbing fittings, boat fittings, propellers, propeller hubs, blades, engine framing, pump liners, valve seats, shaft nuts and caps, and composition castings requiring great strength.

## ROLLED MONEL METAL, SHEETS, PLATES, RODS, BARS, ETC., OR COMPOSITION Mo-r

### NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Scrap.**—Scrap will not be used in the manufacture, except such as may accumulate in the manufacturers' plants from material of the same composition of their own make.

3. **Chemical and Physical Properties.**—The chemical and physical requirements shall be as follows:

| | Per Cent | | Per Cent |
|---|---|---|---|
| Copper | Rem. | Iron (maximum) | 3.5 |
| Tin | | Nickel (minimum) | 60.0 |
| Zinc | | Aluminum (maximum) | .5 |
| Lead (maximum) | 0.0 | | |

| Thickness | Ultimate Tensile Strength per Square Inch | Yield Point per Square Inch | Elongation in 2 Inches |
|---|---|---|---|
| | *Pounds* | *Pounds* | *Per Cent* |
| 1 inch and below | 84,000 | 47,000 | 25 |
| Above 1 inch to 2½ inches | 80,000 | 45,000 | 28 |
| Above 2½ inches | 75,000 | 40,000 | 32 |

No material less than ¼ inch in thickness or diameter need be tested physically.

4. **Additional Tests.**—All bars to be clean and straight, of uniform color, quality, and size. Bars must stand:

(a) Being hammered hot to a fine point.

(b) Being bent cold through an angle of 120° and to a radius equal to the diameter or thickness of the test bar.

The bending test bar may be the full-size bar, or the standard bar of 1 inch width and ½ inch thickness. In the case of bending test pieces of rectangular section, the edges may be rounded off to a radius equal to one-fourth of the thickness.

5. **Surface Inspection.**—Material must be free from all injurious defects, clean, smooth, must lie flat, and be within the gauge and weight tolerances.

6. **Trimming.**—Plates and sheets will be cut to the required dimensions and will be ordered in as narrow widths as can be used.

(a) The following will be considered stock lengths for Monel metal sheets when ordered in 10-foot lengths:

40 per cent in weight may be in 8- to 10-foot lengths.

30 per cent in weight may be in 6- to 8-foot lengths.

20 per cent in weight may be in 4- to 6-foot lengths.

10 per cent in weight may be in 2- to 4-foot lengths.

No lengths less than 2 feet will be accepted, and the total weight of all pieces on lengths less than 10 feet must not exceed 40 per cent in any one shipment.

(b) Rods and bars, when ordered to any length, will be received in stock lengths,

unless it is specifically stated that the lengths are to be exact. Stock lengths will be as follows:

When ordered in 12-foot lengths, no lengths less than 8 feet.

When ordered in 10-foot lengths, no lengths less than 6 feet.

When ordered in 8-foot lengths, no lengths less than 6 feet.

When ordered in 6-foot lengths, no lengths less than 4 feet.

When ordered to the lengths given above, the weight of lengths less than length ordered shall not exceed 40 per cent of any one shipment.

This applies to all rods from $\frac{1}{4}$ to 1 inch diameter or thickness. whether round, rectangular, square, or hexagonal. Above 1 inch to and including 2 inches the lengths will be random lengths from 4 feet to 10 feet. Above 2 inches the lengths are special, but no length will be less than 4 feet.

7. **Tolerances.**—No excess weight will be paid for, and no single piece that weighs more than 5 per cent above the calculated weight will be accepted.

UNDERWEIGHT AND GAUGE TOLERANCES

| | Tolerance |
|---|---|
| Width of sheets or plates | *Per Ct.* |
| Up to 48 inches | 5 |
| 48 to 60 inches | 7 |
| Over 60 inches | 8 |

Material shall not vary throughout its length or width more than the given tolerance.

8. **Fracture.**—The color of the fracture section of test pieces and the grain of the material must be uniform throughout.

9. **Purposes for Which Used.**—The material is suitable for the following purposes: Rolled rounds, used principally for propeller-blade bolts, air-pump and condenser bolts, and parts requiring strength and incorrodibility, and pump rods.

## BENEDICT NICKEL, ROLLED, OR COMPOSITION Be-r

### NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Scrap.**—Scrap will not be used, except such as may result from the process of manufacture of articles of similar composition.

3. **Chemical Properties.**—The chemical requirements shall be as follows:

| Copper, per Cent | Tin, per Cent | Iron, per Cent | Iron, per Cent Maximum | Lead, per Cent, Maximum | Nickel |
|---|---|---|---|---|---|
| 84–86 | .......... | .......... | .......... | .......... | Remainder |

4. **Supersedes.**—This specification supersedes composition Be-r in Specification Part II, Steam Engineering (Revised July 1, 1910).

5. **Purposes for Which Used.**—The material is suitable for the following purposes: Tubes for condenser distillers and feed-water heaters.

## GERMAN SILVER, OR COMPOSITION G-Ag

NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Scrap.**—Scrap will not be used, except such as may result from the process of manufacture of articles of similar composition.

3. **Chemical Properties.**—The chemical requirements shall be as follows:

| Copper | Tin | Zinc | Nickel | Iron | Lead | Sulphur |
|---|---|---|---|---|---|---|
| *Per Cent* 64 | ....... | *Per Cent* 20 | *Per Cent* 16 | Trace only | Trace only | Trace only |

4. **Workmanship.**—Material must be in accordance with detail specifications and free from all injurious defects.

5. **Fracture.**—The color of the fracture section of test pieces and the grain of the metal must be uniform throughout.

## SPECIFICATIONS FOR THE INSPECTION OF COPPER, BRASS, AND BRONZE

Under the Cognizance of the Bureau of Construction and Repair

NAVY DEPARTMENT

### DESIGNATION OF CONTRACTOR, MANUFACTURER, AND SUBCONTRACTOR

1. **Contractor.**—Generally speaking, contractor, as used in these specifications, refers to ship-yard, navy-yard, or any builder of Government machinery, appliances, or structures placing orders for material with some manufacturer.

2. **Manufacturer.**—Refers to person or firm manufacturing material for incorporation in Government work being done by ship-yard, navy-yard, or any other builder of Government machinery, appliances, or structures, and who are designated as contractors.

3. **Subcontractor.**—Refers to person or firm to whom the contractor may sublet part of his contract, but not for raw material; the subcontractor in turn places orders with manufacturers for raw material.

### OFFICE AND INSPECTORS

4. **Access to Work and Information.**—The Department shall have the right to keep inspectors at the works who shall have free access at all times to all parts thereof and be permitted to examine the raw material and to witness the process of manufacture.

Contractors and manufacturers shall furnish all the information and facilities the inspector may require for proper inspection under these specifications.

5. **Inspector's Office and Furniture.**—Each firm manufacturing material shall, if required, furnish the inspectors, free of expense, with suitable office and laboratory room and such plain office furniture as may be necessary for the proper transaction of their business as agents of the Government.

### EXPENSE

6. **Handling Material.**—All handling of material necessary for purposes of inspection shall be done at the expense of the contractor.

7. **Making Tests.**—All test specimens necessary for the determination of the qualities of material used shall be prepared and tested at the expense of the contractor.

## REJECTION AFTER LEAVING MANUFACTURER

8. **Rejection at Builder's.**—Material may be rejected at the building or navy-yards for surface or other defects, either existing on arrival or developed in working, although it bears the above-mentioned stamps.

## ORDERS, LISTS, AND INVOICES

9. Contractors shall furnish the superintending constructor with copies in duplicate of their orders to manufacturers for material requiring inspection, and such orders shall be given separately for each vessel under contract and shall include the estimated weight of each object or group of similar objects on the schedule. Such orders shall state clearly the grade or kind of material and for what purpose each item called for is intended. Manufacturers shall exhibit to the inspectors the schedules of material that they receive from the contractors, and give the inspectors all the information that the latter may require for the proper inspection of the material on said schedules under these specifications. They shall also furnish every facility to the inspectors, so that they will not be delayed in their work of inspection.

10. **Shipping Report.**—The inspector will forward a copy of each shipping report to the Superintending Constructor at place to which material is shipped. If material is intended for a navy-yard or naval station, the inspector will forward a copy of each shipping report to the Bureau of Construction and Repair, and also a copy to the commandant of the navy-yard or naval station, this copy to be forwarded with a letter. Shipping reports forwarded by the inspector of material must show explicitly on each copy of same the stamp or stamps which appear on the material inspected, or on the casing containing the material, or on tags on car in which the material is shipped, and must state on what part of material, box, or car the stamp is placed.

## STAMPS

11. Each object made from accepted material shall be clearly and indelibly marked with four separate stamps: First, the private stamp of the inspector; secondly, the stamp of the manufacturer; thirdly, identification number, and fourthly, the regulation Government stamp. The last shall not be stamped on any of the above material until it has been inspected, weighed, and passed ready for shipment. In case of small articles passed and packed in bulk, the above-mentioned stamps shall be applied to the boxing or packing material of the object.

12. No material will be received at the building or navy-yards for incorporation into vessels unless it bears, either upon its surface or that of its packing, all these stamps as evidence that it has passed the required Government inspection.

13. **Carload Lots—Tags.**—If the material is shipped in box cars containing no other freight, it will be sufficient to seal the car and put the stamp on the seal as well as on a tag on the inside of the car near the door.

## GENERAL QUALITY

14. **General Character of Material.**—All material shall be of domestic manufacture and of uniform quality throughout the mass of each object, and free from all defects.

15. **Special Material or Special Treatment.**—With the approval of the Bureau of Construction and Repair, special material or special treatment, or both, may be used to obtain the qualities specified.

## GENERAL TEST REQUIREMENTS

16. **Tests and Acceptance.**—All material for which tests are prescribed shall be inspected and tested by Government inspectors and passed by them, subject to restrictions mentioned herein, before acceptance by the Navy Department.

17. **Treatment of Test Pieces.**—Test pieces, after being cut from the plate or object to be tested, shall not be subjected to any treatment or process except machining to

size; and such pieces shall not be cut off until the plate or object shall have received final treatment, except in those special cases mentioned in the following specifications.

18. **Flaws in Test Pieces.**—Test pieces which show defective machining or which after breaking show flaws, or which break outside of the measuring points, may be discarded, and the inspector will select others in their stead.

19. **Test Pieces for Lots.**—Test pieces which represent groups or lots shall be taken, as nearly as the case will permit, so as to represent the worst material in that lot.

20. **Location of Test Pieces.**—All test pieces of rolled bars which are too large to be pulled in their full sizes shall, unless otherwise specified, be taken at a distance from the longitudinal axis of the object equal to one-quarter of the greatest transverse dimension of the body of the object, not including palms and flanges.

The test pieces should be taken from a part of the material which, with the exception of palms or flanges, has not been reduced by forging or rolling more than any other part of that piece of material.

## CHEMICAL ANALYSIS

21. **Contractor's Analysis.**—The character of the castings will generally be determined, knowing the ingredients of the mix and the local foundry practice, by an examination of the fractures where gates are broken off, or by the hammering, bending, etc., of coupons cast on, and from contractor's analysis, a copy of which shall be furnished to the inspector.

22. **Government's Analysis.**—Should the circumstances make it necessary, arrangement will be made by the Bureau for further analysis, at a navy-yard or elsewhere.

Drillings for analysis must be fine, clean, dry, and free from scale. The inspector may take them from any test piece, or from any part of the material, provided in this last case that by so doing the material will not be rendered unfit for use. Unless otherwise requested, the chemist will make determinations of those elements only which are limited by the specifications.

## ADDITIONAL TESTS

23. **By Bureau's Orders.**—Tests may be prescribed by the Bureau of Construction and Repair for the inspection of material for which tests are not specified herein.

24. **By Inspector's Decision.**—The inspector may make, from time to time, such additional tests as he may deem necessary to determine the uniformity of the material.

## TENSILE TESTS AND TEST PIECES

25. **Interpretation.**—The tensile strength herein specified means the ultimate tensile strength per square inch of original cross-section. The elastic limit may be measured by the drop of the beam or the halt of the gauge of the testing machine. The elongation is that obtained after fracture. In the case of test pieces of rectangular section the reduction of area is to be measured by the product of the average width and thickness of the reduced area and not the minimum width and thickness.

26. **Pulling Speed.**—Each tensile-test piece shall be subjected to a direct tensile stress until it breaks, in a machine of standard manufacture, running at a pulling speed of not less than 1 inch and not more than 5 inches per minute for 8-inch test pieces, and not less than $\frac{1}{2}$ inch and not more than 3 inches per minute for 2-inch pieces.

27. **Uniformity of Section.**—Tensile-test pieces shall be uniform in cross-section between measuring points.

28. **Standard Area and Length.**—Test pieces from castings are to have a length of 2 inches between measuring points and an area of cross-section of 1 square inch. Other tensile-test pieces are to have a length of 8 inches between measuring points, but no test piece shall be less than $\frac{1}{2}$ inch diameter nor less than 2 inches between measuring points.

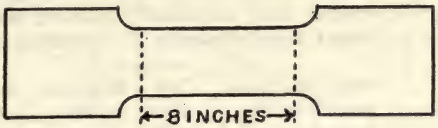
29. **Allowance of Variation in Area of Test Pieces.**—A variation of 5 per cent above or below in area is allowed.

30. **Full-Size Bars.**—Full-size bars and rods within the capacity of the testing

machine may be used as tensile-test pieces, and in this case the bending tests may also be taken from the full-size bars and rods.

31. **Plates, Standard Width for Test Pieces.**—The standard width of tensile-test pieces from plates and tubes will be $1\frac{1}{2}$ inches, the thickness the same as the plate or tube, and the length between measuring points 8 inches.

32. **Rounding of Edges of Test Pieces.**—In the case of bending test pieces of rec-




tangular section the edges may be rounded off to a radius equal to one-fourth of the thickness.

33. **Standard.**—Bending-test pieces shall be 1 inch wide by $\frac{1}{2}$ inch thick. For plates the width shall be not less than $1\frac{1}{2}$ inches and the thickness that of the plate. The bending may be done by either pressure or by blows.

34. **Test Specimens.**—Test specimens, in general, shall be taken from each lot of 200 pounds or less, except in the case of large castings, in which case one specimen shall be taken from each 500 pounds.

## STANDARD REQUIREMENTS FOR ALLOYS OF COPPER, TIN, AND ZINC

35. For the purpose of securing uniformity in practice in castings of the alloys of copper, tin, and zinc for incorporation into naval vessels, the bureau establishes the standard mixtures listed below.

36. Contractors in submitting plans or schedules involving such castings must designate, by name or by mark, the alloy which is proposed for the purpose, being governed by the instructions below as to the uses of the several alloys, and the consideration and approval of the plan will extend to and cover the alloy or composition.

37. With the exception of yellow or scrap brass, all cast alloys shall be made from new materials of purest commercial quality.

### COPPER ALLOYS

38. The various copper alloys and the purposes for which used will be as follows:

| Name | Class | Mixture, per Cent | Purpose |
|---|---|---|---|
| Composition: | | | |
| Gun bronze... | G.... | (Normal 88–10–2.) Copper, 87 to 89; tin, 11 to 9; zinc, remainder. | Valves 4 inches and above, gunport frames, air-port lens frames, manhole fittings, sea chests and strainers, and studs and nuts securing strainers, steering stand, other bronze parts, parts of steering gears, sluice valves and bronze parts of magazine flood cocks and operating gear for both. Composition pipe fittings, stuffing boxes, gear wheels, hardware for joiner work and furniture, cleats and boat fittings, water-closet troughs, and all parts where great strength is required of composition casting. |

Standard Requirements for Alloys—Copper Alloys—*Cont.*

| Name | Class | Mixture, per Cent | Purpose |
|---|---|---|---|
| Valve bronze... | M... | (Normal 87–7–4.) Copper, at least 87; tin, at least 7; lead, not more than 1; zinc, remainder. | Valves below 4 inches, manifolds and cocks, relief valves, composition lug sockets, and pad eyes not requiring special strength. |
| Journal bronze . | H... | (Normal 83–13½–3½.) Copper, 82 to 84; tin, 12.5 to 14.5; zinc, 2.5 to 4.5. | Bearings, bushings, and sleeves, slides, guide gibs, wedges on water-tight doors, and all parts subject to considerable wear. |
| Brazing metal.. | F.... | (Normal 85–0–15.) Copper, 84 to 86; zinc, remainder. | All flanges for copper pipe and other fittings that are to be brazed. |
| Yellow or scrap brass. | S.... | Normal 67–0–33. Copper, 64 to 68; zinc, 32 to 34; lead, not over 2½; iron, not over 2. | Fixed parts of air-port frames, deck drains and gratings, hatch and scuttle covers, deadlight shutters, light box castings, handwheels, deck plates, pipe stuffing tubes, caps for thermometer tubes, cast parts of scuppers and pipes, truck light pedestals, pin rails, label plates, caps or ornamental finishing castings, guards for heater and other pipes, voice-pipe fittings, chocks and fair leads, sheaves, toe plates and head and heel fittings for ladders, and miscellaneous boat fittings. |
| Naval brass, cast. | N-c.. | (Normal 62–1–37.) Copper, 61 to 63; tin, 1 to 1.5; zinc, remainder. | Hatch frames, hatch-cover frames, door frames, scuttle frames, fittings for mess tables and benches; skylight and chest hinges and fittings; all joiner work fittings (except hardware); rail and ladder stanchions, brackets, clips, etc., for stowage purposes; fittings for canopy frames; all brass valves and fittings of ventilation system, except working parts, belaying pins, tarpaulin hooks, brass hatch and door fittings, brass pipe flanges. |
| Naval brass, rolled. | N-r.. | As approved. Analysis of commercial bars shows: Copper, 64 to 67; tin, 0.7 to 0.8; zinc, 32 to 35 | Bolts, studs, nuts, and turn-buckles, especially if subject to corrosion by salt water. |

STANDARD REQUIREMENTS FOR ALLOYS—COPPER ALLOYS—*Cont.*

| Name | Class | Mixture, per Cent | Purpose |
|---|---|---|---|
| Manganese bronze, cast. | Mn-c | As approved; usual composition is: Copper, 56; zinc, 41.38; iron, 1.25; tin, 0.75; aluminum, 0.5; manganese, 0.12. | Castings requiring great strength, such as main gearing in steering engine; wormwheels in windlass or turning gear for turrets. |
| Manganese bronze, rolled. | Mn-r. | As approved............ | Rolled rounds requiring great strength or subject to corrosion by salt water, valve stems. |
| Tobin bronze, rolled. | T.... | As approved; usually: Copper, 59; tin, 2.16; zinc, 38.40; lead, 0.31; iron, 0.11. | Rolled rounds requiring great strength or subject to corrosion by salt water. |
| Phosphor-bronze, cast and rolled. | P.... | Not less than: Copper, 85; tin, 3; phosphorus, 0.01; the balance made up of components suitable to produce maximum strength and to be incorrodible in salt water. | Valve stems and fittings, etc., exposed to the action of salt water; sheating, gears, and driving or main nuts for steering gears. |
| Antifriction metal. | W... | Best refined copper, 3.7; Banca tin, 88.8; regulus of antimony, 7.5; to be well fluxed with borax and rosin in mixing. | All white metal, lined bearings, and bearing surfaces. |
| Muntz metal... | D.... | Copper, 60; zinc, 40...... | Bolts, nuts, etc., subjected to salt water. |
| Other compositions. | ..... | As approved............ | As directed. |

## SPECIAL BRONZES

39. Special authority may be obtained to use manganese, phosphor, Tobin, or other proprietary bronzes in place of gun metal or naval brass.

40. The Superintending Constructor may require bronzes of special characteristics to be employed for items not especially named above or wherever special qualities for specified items are important.

41. These specifications are for the purpose of defining uniformly the kind of metal acceptable for use; they are not intended to modify specific requirements for special bronzes or other metals now or hereafter contained in hull specifications.

## MANGANESE-BRONZE CASTINGS

42. The castings must be sound, clean, free from blow-holes, porous places, cracks, or any other defects which will materially affect their strength or appearance or which indicate an inferior quality of metal.

43. For castings weighing over 200 pounds, test pieces or coupons shall be taken in such number and from such parts of the casting as will thoroughly exhibit the quality of the metal.

44. Castings weighing less than 200 pounds may be tested by lots, each lot to be represented by two test pieces. If the castings are too small for the attachment of coupons, the test pieces may be cast separately from the same metal under as nearly as possible the same condition as the casting.

45. Coupons shall not be detached from castings until they are stamped by the inspector. If the test pieces are cast separately from the casting, they must be cast in the presence of the inspector and stamped by him as soon as they are taken out of the molds.

46. The test pieces shall show an ultimate tensile strength of not less than 60,000 pounds per square inch, an elastic limit of not less than 30,000 pounds per square inch, and an elongation of not less than 20 per cent in 2 inches.

47. The color of the fractured section of the test pieces and the grain of the metal must be uniform throughout.

## PHOSPHOR BRONZE

48. Rounds, whether cast, rolled, or forged, shall have an ultimate tensile strength and elongation of 50,000 pounds and 25 per cent respectively.

NOTE.—The test pieces are to be as nearly as possible of the same diameter as the rounds, or else they are to be not less than one-half an inch in diameter and taken at a distance from the circumference equal to one-half the radius of the round.

49. Phosphor-bronze spring wire shall be hard and elastic.

50. The inspector will take drillings for analyses, and these shall show not less than 85 per cent copper, not less than 3 per cent tin, and not less than 0.01 per cent phosphorus, the balance to be made up of whatever components the manufacturers consider best suited to produce a composition of the maximum strength, and incorrodible in sea water.

## ROLLED NAVAL BRASS

51. All bars are to be cleaned and straightened and must stand:

(a) Being hammered hot to a fine point.

(b) Being bent cold through an angle of 120° and to a radius equal to the diameter or thickness of the bars.

52. If the metal is to be rolled into rods for bolts or other important parts subject to stress, one test piece for every lot of 400 pounds or less shall show the following results:

| Ultimate Tensile Strength per Square Inch | Elastic Limit | Elongation per Cent in 2 Inches |
|---|---|---|
| Not less than 60,000 pounds | At least one-half ultimate tensile strength. | Not less than 25 per cent. |

In the case of large lots the number of test pieces to be left to the judgment of the inspector.

53. Various composition materials, otherwise conforming to the specifications but manufactured under proprietary processes or having proprietary names, will be accepted as coming under this head.

[Paragraphs 51, 52, and 53 have been superseded by new and extended specifications: see "Rolled medium bronze plates up to $\frac{3}{8}$ inch thick, shapes, rivet rounds, and bars." 48B1.]

## ANTI-FRICTION OR WHITE METAL

54. When practicable, the weighing and mixing of the metals will be witnessed by a Government inspector. Otherwise as many chemical analyses will be taken as, in the judgment of the inspector, will show that the material is of the proper composition.

55. If by reason of scarcity Banca tin cannot be procured, another standard brand of tin may be proposed, subject to the approval of the Bureau of Construction and Repair.

## ROLLED COPPER, MUNTZ METAL, AND BRASS SHEETS, PLATES, AND RODS

56. **Material.**—All metals used either alone or in the manufacture of alloys must be of the purest commercial quality. The copper must be Lake copper, or its equivalent.

57. **Analysis.**—The inspector will take drillings for analyses. An analysis of the copper sheets, plates, and rounds and copper for water-closet troughs must show that they contain not less than 99.5 per cent pure copper. An analysis of Muntz metal must show not less than 59 per cent copper and the remainder zinc. An analysis of brass must show that it is of the specified composition, no component varying more than 1 per cent in amount above or below that specified. Sheet brass for ceiling, trim, and similar purposes may be of commercial composition and chemical analysis will not be required.

58. **Surface Inspection.**—The material must be free from all surface defects; in no place of less thickness than ordered, nor of less weight than the calculated weight, taking the weight of 1 cubic inch of hot-rolled copper to be 0.320 pound, 1 cubic inch of cold-rolled copper 0.323 pound, 1 cubic inch of rolled Muntz metal 0.296 pound, and 1 cubic inch of rolled brass 0.297 pound to 0.313 pound, according to its composition. The sheets and plates must be cut to the dimensions ordered.

59. **Tolerance for Excess of Weights.**—An excess of weight of 5 per cent will be allowed.

## COPPER PIPES

60. **Material.**—The pipe must be made of Lake copper, or its equivalent, and a chemical analysis must show that the metal is 99.5 per cent pure copper. The Government inspector will take drillings for analyses.

61. **Form and Surface.**—The pipe must be free from identations, cracks, flaws, or other surface defects, inside and outside, perfectly round, of the specified diameter and thickness in all parts.

62. **Hydraulic Tests.**—Each pipe must withstand an internal hydraulic pressure which will subject the metal to a stress of 6,000 pounds per square inch, the test pressure being calculated by the following formula for thin hollow cylinders, but in no case will a test pressure of over 1,000 pounds per square inch per gauge be required:

$$p = \frac{2ts}{d}, \text{ in which}$$

$p$ = safe internal pressure;
$d$ = inside diameter in inches;
$s$ = safe tensile strength of material = 6,000 pounds per square inch;
$t$ = thickness of pipe in inches.

Every pipe must be perfectly tight under pressure and show no signs of bulging, cracks, flaws, porous places, or other defects.

63. **Bending Tests.**—A strip $1\frac{1}{2}$ inches wide will be taken from each lot of 2,000 pounds or less of pipe and must stand the following tests:

(a) If less than $\frac{1}{2}$ inch thick, it must stand bending flat back cold after being annealed.

(b) If $\frac{1}{2}$ inch or over, it must bend back after being annealed until the ends are parallel and the inner radius of the bend is equal to the thickness of the piece.

(c) In every case the ends of the bending test pieces shall stand hammering down hot and cold to a knife edge without showing signs of cracks. The pipes must be able to stand flanging without defects.

64. **Tensile Tests.**—Pipes of 2 inches inside diameter and over, for high pressures, are to be subject to tensile tests, one piece of pipe from each lot of 1,000 pounds or less being selected to represent the lot. If the pipes are from 2 inches to 6 inches inside diameter, the test pieces are to be cut longitudinally. If over 6 inches inside diameter, they will be cut circumferentially. The test pieces will be heated to a cherry red and straightened when hot, then machined to the shape shown in the sketch, care being taken to have the brazed seam, if any, between the measuring points.

65. For thickness up to and including $\frac{1}{4}$ inch, the width of the narrow part of the test piece shall be about $1\frac{1}{2}$ inches. For thicker pieces the width shall be such as to

give a cross-section of about ½ square inch, but the breadth shall not in any case be less than the thickness. The rolled surfaces are not to be machined, but to be left in their original condition.

66. The test piece must show an ultimate tensile strength after being annealed of at least 28,000 pounds per square inch for all pipe, and an elongation of at least 25 per cent in 8 inches in the case of seamless pipe.

67. **Threading.**—One piece of pipe taken at random from the completed lot (ready for shipment) must stand threading in a satisfactory manner with the usual thread for the size of the pipe.

68. **Weight.**—The weight of every pipe must be at least equal to the calculated weight on a basis of 1 cubic inch of copper pipe weighs 0.320 pound. An excess of weight equal to 5 per cent of the calculated weight will be allowed.

# SEAMLESS BRASS PIPE

## IRON PIPE SIZES, MADE TO CORRESPOND WITH IRON PIPE AND TO FIT IRON-PIPE FITTINGS

69. **Material.**—Pipe shall be made of material of purest commercial quality, compounded from 60 per cent to 70 per cent of pure copper and from 40 per cent to 30 per cent of pure zinc, and not more than 0.5 of 1 per cent of lead, the manufacturer being allowed this variation of composition in order o get the material best suited for the purpose for which it is intended. The Government inspector will take drillings for chemical analyses.

70. **Defects.**—The pipe will be inspected for surface defects and it must be free from cracks, seams, and defects generally.

71. **Hydraulic Tests.**—Each pipe must withstand an internal hydraulic pressure which will subject the metal to a stress of 7,000 pounds per square inch without showing weakness or defects, in accordance with the formula for thin hollow cylinders under tension where

$$p = \frac{2ts}{d}$$

$p$ = safe internal pressure;
$d$ = inside diameter of pipe in inches;
$s$ = safe tensile strength of material = 7,000 pounds per square inch;
$t$ = thickness of pipe in inches;

but no pipe will be tested beyond 1,000 pounds per square inch per gauge, unless specially directed.

72. **Annealing.**—All pipe, unless ordered "hard," is to be annealed sufficiently to prevent fire cracking and to stand the physical tests.

73. **Physical Tests.**—When the pipe is finished (ready for shipment), the inspector will subject 1 per cent of the lot, taken at random, to the following physical tests:

(a) The end of each test pipe must stand being flattened by hammering until the sides are brought parallel, with a curve on the inside at the ends not greater in diameter than twice the thickness of the metal in the pipe, without showing cracks or flaws.

(b) Each test pipe shall have a piece 3 inches long cut from it, which piece when split must stand opening out flat without showing cracks or flaws.

(c) Each test pipe must stand threading in a satisfactory manner with the usual thread for the size of the pipe. When the pipe is ordered "hard" the (a) and (b) tests shall be made on annealed test specimens. These (a), (b), (c) tests shall be made on each of the test pipes, and the test specimens shall be furnished at the contractor's expense. If any of these pipes selected for tests fail, the inspector will select two extra pipes from the same lot and put them through the same test as the pipe that failed, and both of these pipes must be found satisfactory in order that the lot may be passed. The failure to pass satisfactorily any one of the tests marked (a), (b), (c) will reject the lot.

74. **Thickness, Weight, and Marking.**—All pipe shall be up to the gauge ordered.

Each large single pipe, or bundle of small pipes, must be marked with the name of the vessel for which it is intended, or with the number of the order. The standard weight for seamless-drawn brass pipe will be 0.307 pound per cubic inch of material, but a tolerance not to exceed 5 per cent overweight will be allowed.

## NAVAL BRASS, CAST, OR COMPOSITION N-c

NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Scrap.**—Scrap will not be used, except such as may result from the process of manufacture of articles of similar composition.

3. **Chemical Properties.**—The chemical requirements shall be as follows:

| Copper | Tin | Zinc | Iron, Maximum | Lead, Maximum | |
|---|---|---|---|---|---|
| *Per Cent* 60–63 | *Per Cent* .05–1.5 | *Per Cent* Remainder | *Per Cent* 0.06 | *Per Cent* 0.3 | Normal 62–1–37 |

4. **Workmanship.**—Material must be in accordance with detail specifications and free from all injurious defects.

5. **Fractures.**—The color of the fracture section of test pieces and the grain of the metal must be uniform throughout.

6. **Supersedes.**—This specification supersedes composition N-c in Specifications Part II, Steam Engineering (Revised July 1, 1910).

7. **Purposes for Which Used.**—The material is suitable for the following purposes: (C. and R.) Hatch frames, hatch-cover frames, door frames, scuttle frames; fittings for mess tables and benches; skylight and chest hinges and fittings; all joiner work fittings (except hardware); rail and ladder stanchions; brackets, clips, etc., for stowage purposes; fittings for canopy frames; all brass valves and fittings of ventilation system (except working parts); belaying pins, tarpaulin hooks, brass hatch and door fittings, brass pipe flanges.

(S. E.) Valve handwheels, hand-rail fittings, ornamental and miscellaneous castings, and valves in water chests of condensers.

## ROLLED NAVAL BRASS, SHEETS, PLATES, RODS, BARS, AND SHAPES, OR COMPOSITION N-r

NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Scrap.**—Scrap will not be used in the manufacture, except such as may accumulate in the manufacturers' plants from material of the same composition of their own make.

3. **Chemical Properties.**—The chemical and physical requirements shall be as follows:

| Copper | Tin | Zinc | Iron, Maximum | Lead, Maximum |
|---|---|---|---|---|
| *Per Cent* 59–63 | *Per Cent* 0.5–1.5 | *Per Cent* Remainder | *Per Cent* 0.06 | *Per Cent* 0.2 |

**Physical Properties:**

| Thickness | Tensile Strength | Elastic Limit | Elongation in 8 Inches | Elongation in 2 Inches | Bend 120° Cold |
|---|---|---|---|---|---|
| | *Lbs. per Square Inch* | *Lbs. per Square Inch* | *Per Cent* | *Per Cent* | |
| Up to ½ inch.... | 60,000 | 27,000 | 25 | 35 | Radius equals thickness. |
| ½ to 1 inch..... | 58,000 | 26,000 | 28 | 40 | |
| Over 1 inch..... | 54,000 | 25,000 | 28 | 40 | |

No material less than ¼ inch in thickness or diameter need be tested physically.

4. **Test Pieces.**—Test pieces will be as nearly as possible of the same diameter as the rounds, or else they are not to be less than ½ inch diameter and taken at a distance from the circumference equal to one-half the radius of the rounds.

5. **Additional Tests.**—All bars to be clean and straight, of uniform color, quality, and size. Bars must stand:

(a) Being hammered hot to a fine point.

(b) Being bent cold through an angle of 120° and to a radius equal to the diameter or thickness of the test bar.

(c) The bending test bar may be the full-size bar, or the standard bar of 1 inch width and ½ inch thickness. In the case of bending test pieces of rectangular section, the edges may be rounded off to a radius equal to one-fourth of the thickness.

6. **Surface Inspection.**—Material must be free from all injurious defects, clean, smooth, must lie flat, and be within the gauge and weight tolerances.

7. **Trimming.**—Plates and sheets will be cut to the required dimensions and will be ordered in as narrow widths as can be used.

(a) The following will be considered stock lengths for brass sheets when ordered in 10-foot lengths:

40 per cent in weight may be in 8- to 10-foot lengths.
30 per cent in weight may be in 6- to 8-foot lengths.
20 per cent in weight may be in 4- to 6-foot lengths.
10 per cent in weight may be in 2- to 4-foot lengths.

No lengths less than 2 feet will be accepted and the total weight of all pieces on lengths less than 10 feet must not exceed 40 per cent in any one shipment.

(b) Rods and bars, when ordered to any length, will be received in stock lengths, unless it is specifically stated that the lengths are to be exact. Stock lengths will be as follows:

When ordered in 12-foot lengths no lengths less than 8 feet.
When ordered in 10-foot lengths no lengths less than 6 feet.
When ordered in 8-foot lengths no lengths less than 6 feet.
When ordered in 6-foot lengths no lengths less than 4 feet.

When ordered to the lengths given above, the weight of lengths less than length ordered shall not exceed 40 per cent of any one shipment.

This applies to all rods from ¼ to 1 inch diameter or thickness, whether round, rectangular, square, or hexagonal. Above 1 inch to and including 2 inches the lengths will be random lengths from 4 feet to 10 feet. Above 2 inches the lengths are specials but no length will be less than 4 feet.

8. **Proprietary Materials.**—Various composition materials, otherwise conforming to the specifications but manufactured under proprietary processes or having proprietary names, may be submitted in bids for the consideration of the bureau concerned.

9. **Tolerances.**—No excess weight will be paid for, and no single piece that weighs more than 5 per cent above the calculated weight will be accepted.

MUNTZ METAL SHEETS

UNDERWEIGHT AND GAUGE TOLERANCES

| | Width of Sheets or Plates | | |
|---|---|---|---|
| | Under 48 Inches | 48 to 60 Inches | Over 60 Inches |
| Tolerance........................ | 5 per cent...... | 7 per cent...... | 8 per cent. |

Plates and sheets shall not vary throughout their length or width more than the given tolerance.

10. **Fracture.**—The color of the fracture section of test pieces and the grain of the material must be uniform throughout.

11. **Supersedes.**—This specification supersedes Composition N-r in Specifications Part II, Steam Engineering (Revised July 1, 1910).

12. **Purposes for Which Used.**—The material is suitable for the following purposes: Bolts, studs, nuts, and turnbuckles, especially if subject to corrosion or salt water, rolled rounds, used principally for propeller blade bolts, air pump, and condenser bolts and parts requiring strength and incorrodibility, and pump rods, tube sheets, supporting plates, and shafts for valves in water heads.

## MUNTZ METAL, CAST, OR COMPOSITION D-c

NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Scrap.**—Scrap will not be used, except such as may result from the process of manufacture of articles of similar composition.

3. **Chemical Properties.**—The chemical requirements shall be as follows:

| Copper | Tin | Zinc | Iron, Maximum | Lead, Maximum |
|---|---|---|---|---|
| *Per Cent* | *Per Cent* | *Per Cent* | *Per Cent* | *Per Cent* |
| 59–62 | .............. | 38–41 | ............... | 0.6 |

4. **Workmanship.**—The castings must be made in accordance with the drawings and specifications—sound, clean, free from blow-holes, porous places, cracks, or any other defects which will materially affect their strength or appearance or which indicate an inferior quality of metal.

5. **Supersedes.**—This specification supersedes composition D-c in Specification Part II, Steam Engineering (Revised July 1, 1910).

6. **Fracture.**—The color of the fracture section of test pieces and the grain of the metal must be uniform throughout.

## MUNTZ METAL SHEETS, PLATES, RODS, BARS, AND SHAPES OR NON-FERROUS METAL D-r

NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Scrap.**—Scrap will not be used in the manufacture, except such as may accumulate in the manufacturers' plants from material of the same composition of their own make.

3. **Chemical and Physical Properties.**—The chemical and physical requirements shall be as follows:

| Letter | Name | Copper | Tin | Zinc | Lead | Iron | Ultimate Tensile Strength | Yield Point | Elongation In 2 Inches |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | *Maximum* | *Maximum* | *Lbs. per Sq. Inch* | *Lbs. per Sq. Inch* | *Per Cent* |
| D-r... | Muntz metal (rolled) | 59–62 | .... | 38–41 | 0.6 | .... | 40,000 | 20,000 | 25 |

4. **Test Pieces.**—Test pieces will be as nearly as possible of the same diameter as the rounds, or else they are not to be less than ½ inch diameter and taken at a distance from the circumference equal to one-half the radius of the rounds.

5. **Additional Tests.**—All bars to be clean and straight, of uniform color, quality, and size. Bars must stand:

(a) Being hammered hot to a fine point.

(b) Being bent cold through an angle of 120° and to a radius equal to the diameter or thickness of the test bar.

(c) The bending test bar may be the full-size bar, or the standard bar of 1 inch width and ½ inch thickness. In the case of bending test pieces of rectangular section, the edges may be rounded off to a radius equal to one-fourth of the thickness.

6. **Surface Inspection.**—Material must be free from all injurious defects, clean, smooth, must lie flat, and be within the gauge and weight tolerances.

7. **Trimming.**—Plates and sheets will be cut to the required dimensions and will be ordered in as narrow widths as can be used.

(a) The following will be considered stock lengths for Muntz metal sheets when ordered in 10-foot lengths:

40 per cent in weight may be in 8- to 10-foot lengths.
30 per cent in weight may be in 6- to 8-foot lengths.
20 per cent in weight may be in 4- to 6-foot lengths.
10 per cent in weight may be in 2- to 4-foot lengths.

No lengths less than 2 feet will be accepted, and the total weight of all pieces on lengths less than 10 feet must not exceed 40 per cent in any one shipment.

(b) Rods and bars, when ordered to any length, will be received in stock lengths, unless it is specifically stated that the lengths are to be exact. Stock lengths will be as follows:

When ordered in 12-foot lengths, no lengths less than 8 feet.
When ordered in 10-foot lengths, no lengths less than 6 feet.
When ordered in 8-foot lengths, no lengths less than 6 feet.
When ordered in 6-foot lengths, no lengths less than 4 feet.

When ordered to the lengths given above, the weight of lengths less than length ordered shall not exceed 40 per cent of any one shipment.

This applies to all rods from ¼ to 1 inch diameter or thickness, whether round, rectangular, square, or hexagonal. Above 1 inch to and including 2 inches the lengths will be random lengths from 4 feet to 10 feet. Above 2 inches the lengths are special, but no length will be less than 4 feet.

8. **Tolerances.**—No excess weight will be paid for, and no single piece that weighs more than 5 per cent above the calculated weight will be accepted.

Underweight and Gauge Tolerances

| | Width of Sheets or Plates | | |
|---|---|---|---|
| | Up to 48 Inches, Inclusive | 48 to 60 Inches, Inclusive | Over 60 Inches |
| Tolerance.................... | 5 per cent | 7 per cent | 8 per cent |

Material shall not vary throughout its length or width more than the given tolerance.

9. **Fracture.**—The color of the fracture section of test pieces and the grain of the material must be uniform throughout.

10. **Purposes for Which Used.**—The material is suitable for the following purposes: Bolts and nuts not subject to action of salt water.

## COMMERCIAL BRASS CASTINGS, OR COMPOSITION B-c

NAVY DEPARTMENT

1. **General Instructions.**—General instructions for specifications issued by the bureau concerned shall form part of these specifications.

2. **Designation.**—Material under these specifications shall be designated as "Commercial Brass Castings" or "Composition B-c."

3. **Chemical Properties.**—The chemical requirements shall be as follows:

| Copper per Cent, Minimum | Tin per Cent | Zinc per Cent, Minimum | Iron per Cent, Maximum | Lead per Cent, Maximum | Nickel |
|---|---|---|---|---|---|
| 62 | Remainder | 30 | 2 | 3 | Remainder |

4. **Workmanship.**—The castings must be made in accordance with the drawings and specifications—sound, clean, free from blow-holes, porous places, cracks, or any other defects which will materially affect their strength or appearance, or which indicate an inferior quality of metal.

5. **Fracture.**—The color of the fracture section of test pieces and the grain of the metal must be uniform throughout.

6. **Purposes for Which Used.**—The material is suitable for the following purposes: Name and number plates. Cases for instruments. Oil cups. Distribution boxes.

## COMMERCIAL BRASS FOR RODS, BARS, SHAPES, SHEETS, PLATES, AND PIPING

Or Non-ferrous Metal B-r, when intended for Rods, Bars, and Shapes; Non-ferrous Metal B-p, when intended for Sheets, Plates, and Piping

NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Scrap.**—Scrap will not be used in the manufacture, except such as may accumulate in the manufacturers' plants from material of the same composition of their own make.

3. **Chemical and Physical Properties.**—The chemical and physical requirements shall be as follows:

| Letter | Name | Copper | Tin | Zinc | Lead, Maximum | Iron, Maximum | Ultimate Tensile Strength, Lbs. per Square Inch | Yield Point, Lbs. per Square Inch | Elongation in Two Inches |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | *Per Ct.* |
| B-r... | Commercial brass (rods, bars, and shapes). | 60–63 | 0.5 max. | 38–35½ | 3 | 0.06 | ........ | ...... | ...... |
| B-p... | Commercial brass (for sheets, plates, and piping). | 60–70 | .... | 40–30 | 0.5 | .06 | ........ | ...... | ...... |

4. **Surface Inspection.**—Material must be free from all injurious defects, clean, smooth, must lie flat, and be within the gauge and weight tolerances.

5. **Trimming.**—Plates and sheets will be cut to the required dimensions and will be ordered in as narrow widths as can be used.

(a) The following will be considered stock lengths for commercial brass sheets when ordered in 10-foot lengths:

40 per cent in weight may be in 8- to 10-foot lengths.
30 per cent in weight may be in 6- to 8-foot lengths.
20 per cent in weight may be in 4- to 6-foot lengths.
10 per cent in weight may be in 2- to 4-foot lengths.

No lengths less than 2 feet will be accepted, and the total weight of all pieces on lengths less than 10 feet must not exceed 40 per cent in any one shipment.

(b) Rods and bars, when ordered to any length, will be received in stock lengths, unless it is specifically stated that the lengths are to be exact. Stock lengths will be as follows:

When ordered in 12-foot lengths, no lengths less than 8 feet.
When ordered in 10-foot lengths, no lengths less than 6 feet.
When ordered in 8-foot lengths, no lengths less than 6 feet.
When ordered in 6-foot lengths, no lengths less than 4 feet.

When ordered to the lengths given above, the weight of lengths less than length ordered shall not exceed 40 per cent of any one shipment.

This applies to all rods from $\frac{1}{4}$ to 1 inch diameter or thickness, whether round, rectangular, square, or hexagonal. Above 1 inch to and including 2 inches the lengths will be random lengths from 4 feet to 10 feet. Above 2 inches the lengths are special, but no length will be less than 4 feet.

6. **Tolerances.**—No excess weight will be paid for, and no single piece that weighs more than 5 per cent above the calculated weight will be accepted.

UNDERWEIGHT AND GAUGE TOLERANCES

| | Width of Sheets or Plates | | |
|---|---|---|---|
| | Up to 48 Inches, Inclusive | 48 to 60 Inches, Inclusive | Over 60 Inches |
| Tolerance | 5 per cent | 7 per cent | 8 per cent |

Material shall not vary throughout its length or width more than the given tolerance.

7. **Fracture.**—The color of the fracture section of test pieces and the grain of the material must be uniform throughout.

8. **Purposes for Which Used.**—The material is suitable for the following purposes:

Sheet brass: For liners, trim, etc.
Brass pipe: Handrails.
Distributing oil tubes and water pipes.
Commercial brass rod for trim and purposes where strength and incorrodibility are not required.

## BRASS CASTINGS FOR ELECTRICAL APPLIANCES OR COMPOSITION BE

NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Scrap.**—Scrap will not be used, except such as may result from the process of manufacture of articles of similar composition.

3. **Chemical Properties.**—The chemical requirements shall be as follows:

| Copper | Tin | Zinc | Iron, Maximum | Lead, Maximum |
|---|---|---|---|---|
| *Per Cent* | *Per Cent* | *Per Cent* | *Per Cent* | *Per Cent* |
| 80–88 | 2 min. | Remainder | .............. | 2 |

4. **Workmanship.**—The castings must be made in accordance with the drawings and specifications—sound, clean, free from blow-holes, porous places, cracks, or any other defects which will materially affect their strength or appearance or which indicate an inferior quality of metal.

5. **Fracture.**—The color of the fracture section of test pieces and the grain of the metal must be uniform throughout.

6. **Purposes for Which Used.**—The material is suitable for electrical fittings, such as junction boxes, switches, distribution boxes, connection boxes, water-tight bells and buzzers, etc.

## ADMIRALTY METAL, CAST, OR COMPOSITION A

### NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Designation.**—Material under these specifications shall be designated as "Admiralty Metal" or "Composition A."

3. **Scrap.**—Scrap will not be used, except such as may result from the process of manufacture of articles of similar composition.

4. **Chemical Properties.**—The chemical requirements shall be as follows:

| Copper per Cent, Minimum | Tin, per Cent, Minimum | Zinc, per Cent, | Iron per Cent, Maximum | Lead per Cent, Maximum |
|---|---|---|---|---|
| 70 | 1 | Remainder | 0.06 | 0.075 |

5. **Workmanship.**—The castings must be made in accordance with the drawings and specifications—sound, clean, free from blow-holes, porous places, cracks, or any other defects which will materially affect their strength or appearance or which indicate an inferior quality of metal.

6. **Fracture.**—The color of the fracture section of test pieces and the grain of the metal must be uniform throughout.

7. **Purposes for Which Used.**—The material is suitable for the following purposes:

Condenser tubes.
Distiller tubes.
Feed-water heater tubes.
Evaporator tubes.

## BRAZING METAL OR COMPOSITION F

### NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Scrap.**—Scrap will not be used expect such as may result from the process of manufacture of articles of similar composition.

3. **Chemical Properties.**—The chemical requirements shall be as follows:

| Copper | Tin | Zinc | Iron, Maximum | Lead, Maximum |
|---|---|---|---|---|
| *Per Cent* | *Per Cent* | *Per Cent* | *Per Cent* | *Per Cent* |
| 84–86 | ............. | Remainder | 0.06 | 0.3 |

4. **Workmanship.**—The castings must be made in accordance with the drawings and specifications—sound, clean, free from blow-holes, porous places, cracks, or any other defects which will materially affect their strength or appearance or which indicate an inferior quality of metal.

5. **Fracture.**—The color of the fracture section of test pieces and the grain of the metal must be uniform throughout.

6. **Supersedes.**—These specifications supersede specifications for brazing metal in Steam Engineering Specifications Part II, Revised July 1, 1910.

7. **Purposes for Which Used.**—The material is suitable for the following purposes: All flanges for copper pipe and other fittings that are to be brazed.

## MELTING-POINTS OF COPPER ALLOYS

BUREAU OF MINES

Non-ferrous alloys occur so frequently in machine construction that, in the investigation of current melting practice in American brass foundries, H. W. Gillett and A. B. Norton, acting under the direction of the Bureau of Mines, found it necessary to determine with approximate exactness the true relation between the pouring and melting points of various copper alloys; the available literature on the subject being incomplete and not always trustworthy. The results of their investigations are incorporated in the Bureau's Technical Paper 60, from which the following memoranda are taken.

### METHODS USED IN THE TESTS

The alloys were melted in a gas furnace. Instead of crucibles of the ordinary shape, which exposes too large a surface to volatilization and oxidation, the crucibles used were made from bonded carborundum tubes about 4.5 cm. inside diameter and had walls about 8 mm. thick.

The temperatures were measured by a platinum, platinum-rhodium thermocouple used with a single-pivot galvanometer. The calibration was checked and found correct within the error of reading.

About 600 grams of metal were used in making the tests. The metals were weighed in the proper proportions to form the alloy desired, a slight excess of zinc, increased with increasing zinc content, being allowed to compensate for volatilization. Electrolytic copper, Bertha zinc, and chemically pure lead and tin were used. The copper was melted first, and then covered with granular carbon and a little salt. When the copper was melted the tin, the lead, and lastly the zinc, were added, and the alloy was well stirred with a graphite rod.

When the alloy was fully melted and mixed the pyrometer was inserted and so clamped that the graphite boot did not touch the bottom or sides of the crucible. The gas flame was lowered and the temperature read every 15 seconds, the melt being stirred between each reading. When the alloy had frozen, the gas was turned up and a heating curve was taken. This procedure was repeated several times. Zinc was continually volatilized from the melts containing zinc, but not in sufficient quantity to have appreciable effect on the melting point, as duplicate runs agreed within 5° C. in all cases. After a run was completed, the melt was usually poured into an ingot mold, sampled, and analyzed. As the analyses of the samples analyzed agreed well with the composition desired, the melts containing zinc were not analyzed. Duplicate analyses of the same sample agreed within 0.1 per cent.

All the melts were made from virgin metals except a sample of manganese bronze which was in the form of test-bar ends from a previous investigation. It had shown

a tensile strength of 76,000 to 77,000 pounds per square inch and an elongation of 24 to 35 per cent in the standard brick-form test bar. The bronze had approximately the following composition: Copper, 56 per cent; zinc, 41 per cent; iron, 1.5 per cent; tin, 0.9 per cent; aluminum, 0.45 per cent; and manganese, 0.15 per cent.

The melting point given is the liquidus, or point at which freezing begins on cooling and liquefaction ends on heating. This is more strongly marked than the solidus, or point at which freezing ends on cooling and liquefaction begins on heating.

## RESULTS OF TESTS

The data obtained in the determination of the melting points of several alloys were as follows:

MELTING-POINT DETERMINATION FOR 10 ALLOYS

| Alloy | Composition Desired | | | | Composition by Analysis | | | | Number of Duplicate Determinations | Melting Point (Liquidus) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cu. | Zn. | Sn. | Pb. | Cu. | Zn. | Sn. | Pb. | | | |
| | P. Ct. | P. Ct. | P. Ct. | P. Ct. | P. Ct. | P. Ct. | P. Ct. | P. Ct. | | °C. | °F. |
| Gun metal | 88 | 2 | 10 | .... | .... | .... | .... | .... | 4 | 995 | 1,825 |
| Leaded gun metal | 85½ | 2 | 9½ | 3 | 85.4 | 1.9 | 9.7 | 3.0 | 6 | 980 | 1,795 |
| Red brass | 85 | 5 | 5 | 5 | .... | .... | .... | .... | 8[1] | 970 | 1,780 |
| Low-grade red brass | 82 | 10 | 3 | 5 | 81.5 | 10.4 | 3.1 | 5.0 | 4 | 980 | 1,795 |
| Leaded bronze | 80 | .... | 10 | 10 | .... | .... | .... | .... | 3 | 945 | 1,735 |
| Bronze with zinc | 85 | 5 | 10 | .... | 84.6 | 5.0 | 10.4 | .... | 4 | 980 | 1,795 |
| Half yellow, half red | 75 | 20 | 2 | 3 | 75.0 | 20.0 | 2.0 | 3.0 | 3 | 920 | 1,690 |
| Cast yellow brass | 67 | 31 | .... | 2 | 66.9 | 30.8 | .... | 2.3 | 4 | 895 | 1,645 |
| Naval brass | 61½ | 37 | 1½ | .... | 61.7 | 36.9 | 1.4 | .... | 5 | 855 | 1,570 |
| Manganese bronze | .... | .... | .... | .... | .... | .... | .... | .... | 6 | 870 | 1,600 |

[1] Two Samples.

As the results all checked within 5° C., an allowance of ±10° C. or ±20° F. is probably ample to cover all errors in reading, calibrating, and using the pyrometer.

## PREVIOUSLY DETERMINED MELTING POINTS OF BINARY ALLOYS

For comparison, the melting-point (liquidus) figures for binary systems of copper-tin, copper-zinc, and copper-lead alloys for the range covering the common industrial alloys are given below. As the curves are small, the figures are only accurate to within about ±10° C. or ±20° F.

MELTING POINTS OF BINARY ALLOYS

COPPER-TIN ALLOYS

| Parts by Weight | | Melting Point | |
|---|---|---|---|
| *Copper* | *Tin* | °C | °F |
| 95 | 5 | 1,050 | 1,920 |
| 90 | 10 | 1,005 | 1,840 |
| 85 | 15 | 960 | 1,760 |
| 80 | 20 | 890 | 1,635 |

COPPER-LEAD ALLOYS

| *Copper* | *Lead* | °C | °F |
|---|---|---|---|
| 95 | 5 | 1,065 | 1,950 |
| 90 | 10 | 1,050 | 1,920 |
| 85 | 15 | 1,035 | 1,895 |

COPPER-ZINC ALLOYS

| Parts by Weight | | Melting Point | |
|---|---|---|---|
| *Copper* | *Zinc* | °C | °F |
| 95 | 5 | 1,070 | 1,960 |
| 90 | 10 | 1,055 | 1,930 |
| 85 | 15 | 1,025 | 1,880 |
| 80 | 20 | 1,000 | 1,830 |
| 75 | 25 | 980 | 1,795 |
| 70 | 30 | 940 | 1,725 |
| 65 | 35 | 915 | 1,660 |
| 60 | 40 | 890 | 1,635 |

Although the melting points of only 11 alloys were determined, the alloys chosen represent a large proportion of the non-ferrous alloys in use in the ordinary foundry. The composition of many of the other common alloys is near enough to these or to the binary alloys whose melting points are given to allow the melting point being obtained by interpolation closely enough for most technical purposes.

## ANTI-FRICTION METAL, CAST, OR COMPOSITION W

### NAVY DEPARTMENT

1. **General Instructions.**—General instructions or specifications issued by the bureau concerned shall form part of these specifications.

2. **Scrap.**—Scrap will not be used, except such as may result from the process of manufacture of articles of similar composition.

3. **Chemical Properties.**—The chemical requirements shall be as follows:

| Copper | Tin | Zinc | Iron, Maximum | Lead, Maximum | Regulus of Antimony |
|---|---|---|---|---|---|
| *Per Cent* | *Per Cent* | *Per Cent* | *Per Cent* | *Per Cent* | |
| 3.7 | 88.8 Banca | ........... | ........... | ........... | 7.5* |

* To be well fluxed with borax and rosin in mixing.

4. **Workmanship.**—Material must be in accordance with detail specifications and free from all injurious defects.

5. **Brand of Tin.**—If by reason of scarcity Banca tin cannot be procured, another standard brand of tin may be proposed, subject to the approval of the Bureau of Steam Engineering.

6. **Fracture.**—The color of the fracture section of test pieces and the grain of the metal must be uniform throughout.

7. **Supersedes.**—This specification supersedes Composition W in Specifications Part II, Steam Engineering (Revised July 1, 1910).

8. **Purposes for Which Used.**—The material is suitable for the following purposes: All white metal liner bearings and bearing surfaces.

## SPELTER SOLDER

### NAVY DEPARTMENT

1. **General.**—To be made of high-grade material, of good manufacture, and be suitable for the purpose intended.

2. **Composition.**—To be of the following compositions, as may be specified in requisition:

(a) Long-grain Solder.—To consist of not less than 52 per cent of copper, not more than 0.2 per cent of lead, not more than 0.1 per cent of iron, and the remainder zinc.

(b) Gray Spelter Solder, Quick Running.—To consist of 49 to 52 per cent of copper, 3 to 3.5 per cent of tin, not more than 0.5 per cent of lead, and the remainder zinc.

3. **Containers.**—Long-grain solder shall be delivered in well-made wooden boxes, each containing 100 pounds net weight. Gray spelter solder shall be delivered in 1-pound packages.

4. **Marking.**—Packages and boxes shall be marked with the name of the material, the weight, and the name of the manufacturer.

5. **Deliveries.**—Deliveries shall be marked with the name of the material, the name of the contractor, and the requisition or contract number under which delivery is made.

## SOLDER

### NAVY DEPARTMENT

1. Solder to consist of practically equal amounts, by weight, of lead and tin, and be made from new tin, Straits, Malacca, or Australian, and commercially pure new lead; and be in bars branded "half-and-half" and average about 1 pound.

2. Any bar selected at random from a delivery of solder must show an analysis:

Total tin and lead, not less than 99.8 per cent.

Tin, between 49 and 51 per cent.

Antimony, not more than 0.10 per cent.

Zinc, none.

## CRUCIBLES

### NAVY DEPARTMENT

Crucibles to be of best plumbago or graphite, suitable for melting composition. Workmanship to be of the best. To be delivered in perfect shapes.

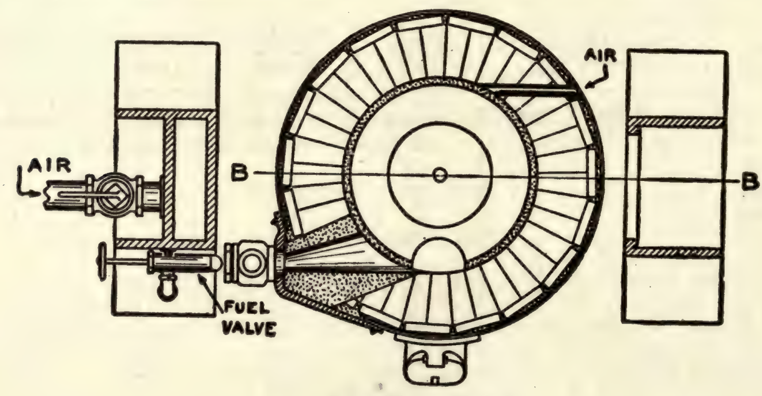
Samples will be selected and must stand a test of at least 20 heats successfully before acceptance. Payment will be made for test crucibles that do not stand 20 heats in the course of inspection at a price bearing the same proportion to the contract price that the number of heats the crucibles stand before breaking bears to 20 heats, the number required, i.e., if the crucibles stand 15 heats and then break, payment of three-fourths of the contract price will be made for such crucibles.

The shapes and outside dimensions to be in accordance with the following dimensions:

| Nos. | Holding Capacity, Liquid Measure | | | Height Outside | Diameter at the Top Outside | Diameter at the Bulge Outside | Diameter at the Bottom Outside |
|---|---|---|---|---|---|---|---|
| | *Gals.* | *Qts.* | *Pts.* | *Inches* | *Inches* | *Inches* | *Inches* |
| 0 | .. | .. | ... | 2 | $1\frac{1}{2}$ | $1\frac{5}{8}$ | $1\frac{1}{4}$ |
| 00 | .. | .. | ... | $2\frac{3}{8}$ | $1\frac{7}{8}$ | $1\frac{7}{8}$ | $1\frac{3}{8}$ |
| 000 | .. | .. | ... | $2\frac{1}{2}$ | $1\frac{7}{8}$ | $2\frac{1}{8}$ | $1\frac{1}{2}$ |
| 0000 | .. | .. | ... | 3 | $2\frac{3}{8}$ | $2\frac{1}{2}$ | $1\frac{3}{4}$ |
| 1 | .. | .. | ... | $3\frac{5}{8}$ | $3\frac{1}{8}$ | 3 | $2\frac{1}{4}$ |
| 2 | .. | .. | ... | $4\frac{1}{2}$ | $3\frac{3}{4}$ | $3\frac{5}{8}$ | $2\frac{3}{4}$ |
| 3 | .. | .. | ... | $5\frac{1}{4}$ | $4\frac{1}{4}$ | $4\frac{1}{8}$ | 3 |
| 4 | .. | .. | ... | $5\frac{5}{8}$ | $4\frac{5}{8}$ | $4\frac{1}{2}$ | $3\frac{1}{4}$ |
| 5 | .. | .. | $1\frac{1}{2}$ | 6 | $4\frac{7}{8}$ | $4\frac{3}{4}$ | $3\frac{1}{2}$ |
| 6 | .. | 1 | ... | $6\frac{1}{2}$ | $5\frac{1}{4}$ | $5\frac{1}{8}$ | $3\frac{3}{4}$ |
| 7 | .. | 1 | $\frac{1}{4}$ | $6\frac{3}{4}$ | $5\frac{1}{2}$ | $5\frac{1}{2}$ | 4 |
| 8 | .. | 1 | $\frac{1}{2}$ | $7\frac{1}{4}$ | $5\frac{3}{4}$ | $5\frac{3}{4}$ | $4\frac{1}{4}$ |
| 9 | .. | 1 | $\frac{3}{4}$ | $7\frac{5}{8}$ | 6 | $6\frac{1}{4}$ | $4\frac{1}{2}$ |
| 10 | .. | 1 | 1 | 8 | 6 | $6\frac{1}{2}$ | $4\frac{3}{4}$ |
| 12 | .. | 2 | ... | 8 | $6\frac{1}{4}$ | $6\frac{3}{4}$ | 5 |
| 14 | .. | 2 | 1 | $8\frac{1}{2}$ | $6\frac{3}{4}$ | $7\frac{1}{4}$ | $5\frac{1}{2}$ |
| 16 | .. | 2 | 1 | $8\frac{3}{4}$ | 7 | $7\frac{1}{2}$ | $5\frac{1}{2}$ |
| 18 | .. | 3 | 1 | $9\frac{3}{4}$ | $7\frac{3}{8}$ | 8 | $5\frac{3}{4}$ |
| 20 | 1 | .. | ... | $10\frac{1}{4}$ | $7\frac{3}{4}$ | $8\frac{3}{8}$ | 6 |
| 25 | 1 | .. | 1 | $10\frac{1}{4}$ | 8 | $8\frac{5}{8}$ | $6\frac{1}{4}$ |

CRUCIBLES—*Cont.*

| Nos. | Holding Capacity, Liquid Measure | | | Height Outside | Diameter at the Top Outside | Diameter at the Bulge Outside | Diameter at the Bottom Outside |
|---|---|---|---|---|---|---|---|
| | *Gals.* | *Qts.* | *Pts.* | *Inches* | *Inches* | *Inches* | *Inches* |
| 30 | 1 | 1 | 1 | 11 | $8\frac{5}{8}$ | $9\frac{1}{4}$ | $6\frac{1}{2}$ |
| 35 | 1 | 2 | 1 | $11\frac{5}{8}$ | $9\frac{1}{4}$ | $9\frac{3}{4}$ | 7 |
| 40 | 2 | .. | ... | $12\frac{3}{8}$ | $9\frac{1}{4}$ | $10\frac{1}{4}$ | $7\frac{3}{4}$ |
| 45 | 2 | 1 | ... | 13 | $9\frac{3}{4}$ | $10\frac{1}{2}$ | $7\frac{5}{8}$ |
| 50 | 2 | 3 | ... | $13\frac{1}{2}$ | $10\frac{1}{8}$ | $11\frac{1}{4}$ | $7\frac{7}{8}$ |
| 60 | 3 | .. | ... | 14 | $10\frac{3}{8}$ | $11\frac{5}{8}$ | 8 |
| 70 | 3 | 1 | | $14\frac{1}{2}$ | $10\frac{7}{8}$ | 12 | $8\frac{1}{4}$ |
| 80 | 3 | 2 | 1 | $15\frac{3}{8}$ | $11\frac{1}{8}$ | $12\frac{3}{8}$ | $8\frac{5}{8}$ |
| 90 | 4 | .. | ... | $15\frac{7}{8}$ | $11\frac{1}{2}$ | $12\frac{1}{2}$ | 9 |
| 100 | 4 | 2 | 1 | 16 | $11\frac{7}{8}$ | $13\frac{1}{8}$ | $9\frac{3}{8}$ |
| 125 | 4 | 3 | 1 | $16\frac{5}{8}$ | $12\frac{1}{2}$ | $13\frac{3}{4}$ | $9\frac{1}{2}$ |
| 150 | 6 | 3 | ... | $18\frac{1}{4}$ | $13\frac{1}{4}$ | $14\frac{3}{4}$ | $10\frac{3}{8}$ |
| 175 | 7 | 3 | 1 | $19\frac{1}{2}$ | $14\frac{1}{4}$ | $15\frac{3}{4}$ | $10\frac{3}{4}$ |
| 200 | 9 | 3 | 1 | $20\frac{1}{2}$ | 15 | $16\frac{1}{2}$ | $11\frac{1}{4}$ |
| 225 | 10 | 1 | 1 | $20\frac{3}{4}$ | $15\frac{1}{4}$ | $16\frac{3}{4}$ | $12\frac{1}{2}$ |
| 250 | 10 | 3 | ... | $20\frac{1}{2}$ | $15\frac{1}{4}$ | 17 | $11\frac{3}{4}$ |
| 275 | 11 | 3 | ... | $22\frac{3}{8}$ | 15 | $16\frac{5}{8}$ | $12\frac{1}{2}$ |
| 300 | 12 | 2 | ... | 22 | $16\frac{1}{4}$ | $17\frac{1}{2}$ | $12\frac{1}{2}$ |




SECTION A–A

## KROESCHELL-SCHWARTZ CRUCIBLE FURNACE, TILTING TYPE

This furnace relates to that class of crucible-furnaces in which the fuel (gas or oil) and the air for its combustion are introduced into the furnace-chamber at or near its base; the hot gases of combustion are given a gyratory motion causing them to completely envelop the crucible supported in the chamber, thus heating and melting its contents. In a furnace of this construction the greatest intensity of heat is generated about the lower portion of the crucible and causes its contents to melt from the bottom upwardly, with the advantage of employing the heat of conduction from the lower

molten portion of the mass to the upper solid portion; it thus expedites the melting operation and greatly reduces oxidation, important considerations in melting metals.

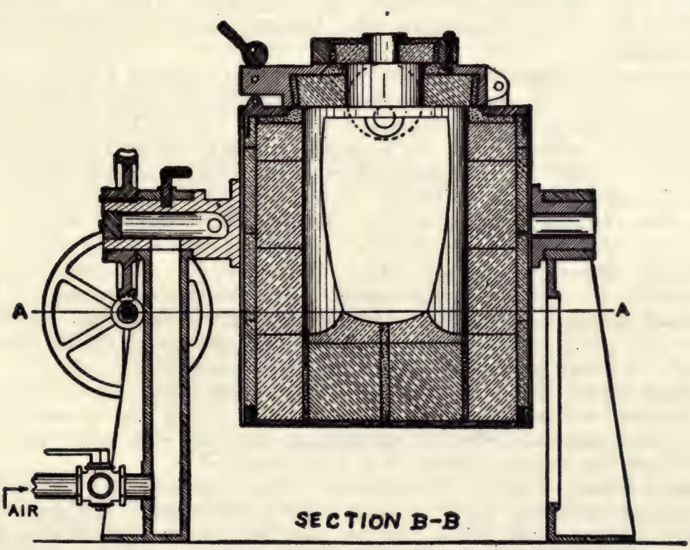
The engravings from designs by Kroeschell Brothers Company, 440 W. Erie Street, Chicago, Ill., show a cylindrical metal casing with refractory lining, as also a raised base formed with a circular concave seat for the purpose of receiving a special crucible having a convex bottom conforming to the seat; it is also provided with a spout for pouring. The crucible is held in place in the furnace by this concave seat and by adjustment of two fire-bricks along the sides and near the top; when the furnace is tipped to pour the metal, the crucible is in no wise displaced, in fact, the crucible is never removed until it has to be replaced by a new one.

This bottom lining also forms an annular gutter having a discharge outlet at the bottom of the casing from which slag or spilled metal discharges automatically, a detail not shown in the engraving.

Two covers are provided, the main cover hinged to top of casing, and a smaller cover arranged to swivel on the main cover as shown in the engraving; both covers are lined with refractory material. The main cover is provided with a central charging opening; the smaller cover is also provided with an opening, the purpose of which is to form an outlet for the escape of spent gases from the furnace. A hood placed above the furnace conveys these gases to the chimney.

To operate the furnace the small cover is swung aside for charging the metal to be melted through the main cover-opening into the crucible. The main cover need never be opened except for introducing and removing a crucible and for repairing purposes, so that the furnace remains closed while in operation and also while pouring.

The furnace is provided with trunnions which rest on two cast-iron supports, the




trunnions being placed below the center to insure the easy tilting of the furnace by means of a hand wheel and gearing when the crucible is filled with metal.

The tilting function of the furnace is advantageous in facilitating pouring the molten metal, and as the crucible is not removed from the furnace, there is no loss of heat through radiation.

Pouring metal from a crucible in a completely closed furnace, far above the temperature of the molten metal, insures not only hot metal but greatly reduces the time required for making the next heat.

The location of fuel valve and air inlet is shown, as also the construction of lining in the combustion zone, in Section A-A.

This tilting furnace is made in one size with melting capacity per heat of 400 pounds of metal. The oil consumption per 100 pounds of brass or bronze melted is 2 gallons; when melting iron 5 gallons of oil are required per 100 pounds. The gas consumption per 100 pounds of brass or bronze is 300 cubic feet; for iron 600 cubic feet of gas are required. The air pressure required is from 20 to 24 ounces. The air required per minute is from 125 to 140 cubic feet.

Melting copper, brass, or bronze, the furnace has a capacity of from six to seven 400-pound heats per day. The oxidation of the non-ferrous metals melted in this furnace is very low; on bronze it is less than 1%, while on yellow brass it is less than 2%. The furnace is especially well adapted for melting borings, turnings, etc., because the metal melts first at the bottom of the crucible; this insures a low melting loss.

When used for melting gray iron, the output averages about 400 pounds per heat, and four heats can readily be taken off in a day. The results thus far obtained with iron have been gratifying. Owing to the fact that the iron does not come in contact with coke or other melting medium, as in the cupola, there is no increase in the sulphur content, and the other metalloids, such as manganese, silicon, and carbon are under absolute control. For this reason, clean iron is insured and no change occurs in the mixture as a result of the melting operation, owing to the low percentage of oxidation.

## COMPOSITION OF SOME ALLOYS USED IN ENGINEERING

### ALPHABETICALLY ARRANGED

**Admiralty Metal.**—Cast. United States Navy. Composition A: 70.0% copper (minimum); 1.0% tin (minimum); 0.06% iron (maximum); 0.075% lead (maximum); zinc = remainder. Uses. Condenser tubes, distiller tubes, feed-water heater tubes, evaporator tubes.

**Aich's Metal.**—Composition: 60.0% copper; 38.2% zinc; 1.8% iron. To which is sometimes added 1.0% tin. Properties: Specific gravity, 8.42. Yellow-gold color. Resists action of sea water; it is hard and tenacious. At red heat it is as malleable as wrought iron. At 20° C. (68° F.) its tensile strength is 57,300 pounds per square inch; at 450° C. (842° F.) the tenacity is reduced to 11,430 pounds per square inch. Melting point about 894° C. (1641° F.)

**Alloy—Non-Oxidizable.**—Composition, Lemarguand: 38.66% copper; 7.22% nickel; 7.73% cobalt; 9.28% tin; 37.12% zinc. The metals must be pure.

**Aluminum Alloy.**—Composition: 3.0% copper; 82.0% aluminum; 15.0% zinc. Specific gravity, 3.1 = 0.11 pound per cubic inch. Suitable for castings.

**Aluminum Alloy.**—Composition: 8.0% copper; 92.0% aluminum. Specific gravity, 2.8 = 0.10 pound per cubic inch. Tensile strength about 18,000 pounds per square inch. Suitable for automobile castings, crank cases, etc.

**Aluminum Alloys.**—Note—Zinc alone confers strength to the alloys with aluminum. Copper hardens without strengthening. Annealing lowers the strength. Rolling strengthens the material. Strength of castings increases with magnesium content, the copper and zinc content ranging 10 to 15% combined.

**Aluminum Brass.**—Cowles. Composition: 33.33% copper; 33.33% zinc; 33.33% A-No. 1 aluminum bronze (89.0% copper; 11.0% aluminum). The copper and the bronze are first thoroughly melted together, then add the zinc. This alloy will show about 80,000 pounds tensile strength per square inch.

**Aluminum Bronze.**—Composition: 87.0% aluminum; 8.0% copper; 5.0% tin. Used in the automobile industry.

Aluminum Bronze. Composition, Cowles: A-No. 1 = 89.0% copper; 11.0% aluminum.

A-No. 2 = 90.0% copper; 10.0% aluminum. These alloys are used in mixtures when preparing aluminum brasses.

**Aluminum Copper.**—Aluminum with less than 7.0% copper will form malleable alloys. In the automobile industry alloys containing 3 to 5.0% copper are sometimes used. An alloy 94.0% aluminum; 6.0% copper was used in the hull construction of a torpedo boat, but the excessive corrosion of this alloy by sea water prevented its

further use. The highest tenacity is obtained with the alloy containing about 4.0% copper; beyond this the strength diminishes. Only those alloys which contain but small percentages of copper are of any industrial value.

**Aluminum and Manganese.**—Alloys may be made by mixing these two metals while in a state of fusion; the resultant alloy will have the property of being attracted by the magnet. Alloys containing 2 to 3.0% manganese are used in the automobile industry. The effect of small quantities of manganese is to increase the tenacity, but when as much as 10.0% is reached the alloys are hard and brittle.

**Aluminum and Nickel.**—The effect of nickel on aluminum is similar to that of copper, but it is only such alloys as contain small percentages of nickel that possess any practical value; the limit appears to be at about 2.0% nickel, which hardens aluminum. At 5.0% nickel the alloy is very brittle.

**Aluminum and Zinc.**—Alloys containing less than 50.0% zinc consist of homogeneous solid solutions, and those containing less than 4.0% aluminum are also solid solutions. Alloys with 1 to 15% zinc can be rolled, and drawn, but with more zinc they become hard and can only be used for castings.

**Anti-Friction Metal.**—Admiralty. Plastic. Composition: 5.0% copper; 85.0% tin; 10.0% antimony. For heavy load (special): 8.0% copper; 83.0% tin; 9.0% antimony.

Anti-Friction Metal.—Cast. United States Navy. Composition W: 3.7% copper; 88.8% tin (Banca); 7.5% regulus of antimony (to be well fluxed with borax and rosin in mixing). Uses. All white metal liner bearings and bearing surfaces.

**Argentan.**—Composition: 52.0% copper; 26.0% nickel; 22.0% zinc.

**Arsenic Bronze.**—Composition by analysis, Dudley. 89.20% copper; 10.0% tin; 0.8% arsenic.

**Babbitt Metal.**—A composition for lining journal boxes was patented by Isaac Babbitt in 1839. In his patent he claimed 50 parts tin; 5 of antimony; and 1 of copper, but did not intend to confine himself to this particular composition. This is the basic formula for all so-called babbitt metals.

Commercial Babbitt metals range from the so-called genuine Babbitt down through a great variety of mixtures to that of simply hardened lead. With a view to reducing the number of commercial mixtures and yet meet the requirements of machine and engine builders, a sub-committee of the American Society for Testing Materials has proposed 5 specific grades, as given below.

| Number | Tin | Antimony | Copper | Lead |
|---|---|---|---|---|
| 1 | 83.33% | 8.33% | 8.33% | ..... |
| 2 | 89.00 | 7.00 | 4.00 | ..... |
| 3 | 50.00 | 15.00 | 2.00 | 33.00% |
| 4 | 5.00 | 15.00 | .... | 80.00 |
| 5 | ..... | 10.00 | ..... | 90.00 |

A Babbitt metal recommended in the Metal Industry Handbook (1916) is made as follows: Melt together 4 pounds copper, 8 pounds antimony, and 24 pounds tin. Cast this in thin strips in an iron mold. Melt in an iron pot 72 pounds tin, and add the hardening mixture to it and stir well. Cast the resulting metal into small ingots for use. The Handbook says this is one of the best white metals for lining bearings known, when it is made according to the above formula.

**Note.**—The above composition is almost identical to that used in the United States Navy.

**Bell Metal.**—Composition: 80.0% copper; 20.0% tin. This metal when slowly cooled after fusion, is dingy gray in appearance, and very brittle. If suddenly chilled in cold water from a low red heat it becomes moderately soft and capable of being worked; it may be hardened after working by heating to redness and slowly cooled.

**Brass with Aluminum.**—The useful addition of aluminum to brass composed wholly of copper and zinc is restricted to small percentages, not over 4%. Guillet's experi-

ments relating to two types of brass known as 70–30 and 60–40 composition show that an alloy containing 38.0% zinc and 2.0% aluminum has the structure of a brass containing 45.0% zinc; and this holds good with all the intermediate alloys; indicating that 1.0% aluminum is probably equivalent to 3.5% zinc. With more than 4.0% aluminum the alloys are difficult to work. It is probable that the action of aluminum in small quantities in compositions of copper and zinc is that of a deoxidizer.

**Brass with Aluminum.**—Castings. Mechanical tests by Guillet show that 60.0% copper; 40.0% zinc, has a tensile strength of 44,800 pounds per square inch with 47.0% elongation. With 0.8% aluminum the tensile strength was about 43,000 pounds, elongation 45%. With 2.9% aluminum the tensile strength was nearly 65,000 pounds, elongation 14%. With 4.7% aluminum the tensile strength was 62,720 pounds, elongation 2%. For engineering purposes the 4.7% alloy is inferior to that containing 2.9% aluminum because of its brittleness.

A brass alloy, 70.0% copper; 30.0% zinc, showed a tensile strength of about 19,264 pounds per square inch with 50.0% elongation. An alloy, 70.0% copper; 29.1% zinc; 0.9% aluminum, had tensile strength 31,800 pounds with 67.0% elongation. With 3.1% aluminum; 70.5% copper; 26.4% zinc, the tensile strength was 47,488 pounds with 50.0% elongation. Increasing the aluminum to 5.2%, with 70.0% copper; 24.8% zinc, the tensile strength was 71,232 pounds with but 11.0% elongation.

**Brass with Aluminum.** Rolled and annealed bars. Mechanical tests by Guillet show that an alloy 61.4% copper; 37.9% zinc; 0.7% aluminum, had a tensile strength of about 49,000 pounds per square inch with 45.0% elongation. An alloy, 61.0% copper; 37.6% zinc; 1.4% aluminum, had 51,520 pounds tensile strength with 45.3% elongation. With 60.0% copper; 38.0% zinc; 2.0% aluminum, the tensile strength was 56,000 pounds with 17.0% elongation. Increasing the aluminum to 3.9% aluminum with 60.0% copper; 36.1% zinc, the tensile strength was about 67,000 pounds with 13.0% elongation.

**Brass Castings.**—United States Navy. Composition B-c: 62.0% copper (minimum); 30.0% zinc (minimum); 2.0% iron (maximum); 3.0% lead (maximum); tin = remainder, normally, 3.0%. Uses: Name and number plates. Cases for instruments. Oil cups. Distribution boxes.

**Brass Castings for Electrical Appliances.**—United States Navy. Composition BE: 80–88% copper; 2.0% tin (minimum); 2.0% lead (maximum); zinc = remainder. Uses: For electrical fittings, such as junction boxes, switches, distribution boxes connection boxes, water-tight bells, and buzzers, etc.

**Brass Castings.** — Not to stand high pressure steam. Composition: 85.0% copper; 15.0% zinc; 3.0% tin; 2.0% lead. Melting point about 1032° C. (1890° F.).

**Brass, Castings, Yellow.**—Composition: 70.0% copper; 1.0% tin; 27.0% zinc; 2.0% lead. Tensile strength, about 29,000 pounds per square inch. Casts satisfactorily, works easily, takes a fine finish.

**Brass, Commercial.** — Compositions B-r and B-p. United States Navy. Composition B-r: 60–63% copper; 0.5% tin (maximum); 38–35.5% zinc; 3.0% lead (maximum) 0.06% iron (maximum). Uses: For rods, bars, shapes.

B-p: 60–70% copper; 40–30% zinc; 0.5% lead (maximum); 0.06% iron (maximum). Uses: For sheets, plates, and piping.

**Brass Condenser Tubes.** — Admiralty. Composition: 70.0% copper; 1.0% tin (minimum); 29.0% zinc.

**Brass with Lead.**—The addition of lead to brass improves its lathe-working qualities. Lead exists in brass in a free state and tends to segregate in patches according to the amount present and the rate of cooling. Quick cooling lessens segregation. High grade brass should never contain more than 0.10% lead or its ductility will be impaired. The presence of 2.5 to 3.0% lead cannot be detected by the eye in a polished surface. Alloys of brass with lead are rolled cold, because of liability to crack if rolled hot, and the limit of lead is about 2.0% for rolling. The alloy most commonly used contains about 60.0% copper; 38.0% zinc; 2.0% lead.

**Brass with Manganese.**—The so-called manganese bronze is in reality a manganese brass; the principal metals in the alloy being copper and zinc. The action of manganese in a copper and zinc alloy is to strengthen and harden it; it is equivalent to reducing the copper and increasing the zinc. As the addition of the manganese is

commonly in the form of ferro-manganese such alloys contain traces of iron, and upon analysis, very often, only traces of manganese are found, in which case the manganese probably acted as a deoxidizer and did not enter into the alloy at all. When manganese does enter into solution, the micro-structure is the same as that of copper-zinc alloys. Manganese bronzes or brasses containing more than 60% copper are suitable for forging; alloys containing less than 60% copper are suitable only for castings. A feature of brass-manganese alloys is instanced by Hiorns in which an alloy: 54% copper; 40% zinc; 6% manganese, has practically the same structure as brass with 57% copper and 43% zinc. Again, an alloy of 55% copper; 10% manganese; 35% zinc, has the same structure as 60–40 brass.

**Brass. Naval. Admiralty.**—Composition: 62.0% copper; 1.0% tin; 37.0% zinc. Tensile strength for round bars, ¾ inch and under 58,240 pounds per square inch; round bars above ¾ inch and square bars, 49,280 pounds. Bars to be capable of (a) being hammered hot to a fine point; (b) being bent cold through an angle of 75° over a radius equal to the diameter, or the thickness of the bars.

**Brass Pipe Fittings.**—United States Navy. Composition S-c: **77–80%** copper; 4.0% tin; 13–19% zinc; 3.0% lead; 0.10% iron.

**Brass. Red. Commercial.**—Composition: 83.0% copper; 4.0% tin; 7.0 zinc; 6.0% lead. Tensile strength about 30,000 pounds per square inch.

**Brass. Rolled. High Brass.**—Composition: 61.5% copper; 38.5% zinc. For spinning, drawing, etc.

**Brass. Rolled. Low Brass.**—Composition: 80.0% copper; 20.0% zinc.

**Brass. Spring Wire.**—Composition: 65.7% copper; 32.8% zinc; 1.5% tin, or, commonly, 66⅔% copper; 33⅓% zinc, with 1½% tin added.

**Brass with Tin.**—A small percentage of tin renders brass less liable to corrosion by sea water when in contact with gun metal. An alloy of brass with tin is known as Naval Brass, the approximate composition being 62.0% copper; 37.0% zinc; 1.0% tin; beyond this percentage of tin the alloy increases in brittleness and hardness; and with more than 2.0% tin the alloy loses its useful properties.

**Brass Tubes for Locomotives.**—British Standard. Composition: 70–30 alloy to contain not less than 70.0% copper, and not more than a total of 0.75% of materials other than copper and zinc.

Composition: 2–1 alloy to contain not less than 66.7% copper, and not more than a total of 0.75% of materials other than copper and zinc.

Bulging test: The tubes must stand bulging or drifting without either crack or flaw, until the diameter of the bulged or drifted end measures not less than 25.0% greater than the original diameter of the tube.

Flanging test: The tubes must stand flanging, without showing either crack or flaw, until the diameter of the flange measures not less than 25.0% greater than the original diameter of the tube.

Flattening and doubling over test: Tubes must be capable of standing the following test, when cold, without showing either crack or flaw. A piece of the tube shall be flattened down until the interior surfaces of the tube meet, and then be doubled over on itself, *i.e.*, bent through an angle of 180°, the bend being at right angles to the direction of length of the tube.

Hydraulic test: All brass boiler tubes shall be tested by an internal hydraulic pressure of at least 750 pounds per square inch.

**Brass, Yellow.** — Composition: 60.0% copper; 40.0% zinc. Tensile strength: Castings = 16,000 pounds per square inch. Annealed sheet = 60,000 pounds. Hard rolled sheet = 107,000 pounds. A possible reduction of 92.0% in rolling is given by E. S. Sperry. This composition is perfectly homogeneous; the chips, being long and tenaceous, necessitate a slow speed in cutting.

Brass, Yellow.—Composition: 60.0% copper; 35.0% zinc; 5.0% lead. Tensile strength: Castings = 33,000 pounds per square inch. Annealed sheets = 42,000 pounds. Hard rolled sheets = 61,000 pounds. This composition makes good castings with good cutting qualities. This alloy cracked on rolling. A possible reduction of 61.0% in rolling is given by E. S. Sperry.

**Brazing. Aluminum Bronze.**—This metal will braze, using 25.0% brass solder

(50.0% copper; 50.0% zinc) and 75.0% borax, or, better perhaps, 75.0% cryolite, a double fluoride of aluminum and sodium.

**Brazing Metal.**—Composition: 84.2% copper; 15.8% zinc. For flanges for copper pipes. Brazing solder for the above alloy, 50.0% copper; 50.0% zinc.

Brazing Metal.—United States Navy. Composition F: 84–86% copper; 0.06% iron (maximum); 0.3% lead (maximum); zinc = remainder. Used on all flanges for copper pipe and other fittings that are to be brazed.

**Bronze. Acid Resisting.**—Composition: 90.0% copper; 10.0% tin. Tensile strength, 37,500 pounds per square inch. Suitable for mine pumps.

**Bronze, Ajax.**—Composition by analysis, Dudley: 81.2% copper; 10.9% tin; 7.2% lead; 0.4% phosphorus.

**Bronze, Castings.**—Admiralty. Composition: 87.0% copper; 8.0% tin; 5.0% zinc. For parts of engines on Naval vessels.

**Bronze, Deoxidized.**—Composition: 82.42% copper; 12.25% tin; 3.14% zinc; 2.08% lead; 0.10% iron; 0.03% silver; 0.005 phosphorus.

**Bronze, Journal.**—United States Navy. Composition H: 82–84% copper; 12.5–14.5% tin; 2.5–4.5% zinc; 0.06% iron (maximum); 1.0% lead (maximum). Normal: 83 – 13.5 – 3.5. Uses: Suitable for bearings, journal boxes, bushings, and sleeves, slides, slippers, guide gibs, wedges on water-tight doors, and all parts subject to considerable wear, for reciprocating engines in valve stem cross-head bottom brass, link block gibs, and suspension link brasses.

**Camelia Metal.**—Composition by analysis, Dudley: 70.2% copper; 4.2% tin; 14.7% lead; 10.2% zinc; 0.5% iron.

**Car Bearings. Pennsylvania Railroad.**—Composition, Dudley's alloy B: 76.8% copper; 8.0% tin; 15.0% lead; 0.2% phosphorus.

**Carbon Bronze.**—Composition by analysis, Dudley: 75.4% copper; 9.7% tin; 14.5% lead.

**Constantin.**—Composition: 60.0% copper; 40.0% nickel. High electric resistance properties.

**Copper Plates** for locomotive fire boxes. English Standard. Composition: Class A. Not less than 99.25% copper, and 0.35 to 0.55% of arsenic.

Class B. Not less than 99.25% copper, and 0.25 to 0.45% of arsenic. Tensile strength not less than 31,360 pounds per square inch with 35% elongation in 8 inches. Bending test both red and cold through 180° without showing either crack or flaw on the outside of the bend.

**Copper Rods** for locomotive stay bolts, rivets, etc. English Standard. Composition: Not less than 99.25% copper, and 0.15 to 0.35% of arsenic. Tensile strength not less than 31,360 pounds per square inch with not less than 40.0% elongation in 8 inches.

**Copper Tubes** (seamless) for locomotive feed pipes etc. British Standard. Composition: Tubes must contain not less than 99.25% copper, and 0.25 to 0.45% arsenic. Mechanical tests are the same as for brass tubes.

**Cupro-Nickel.**—For cartridge cases: 75.0 to 85.0% copper and the remainder nickel.

**Delta Metal.** Composition: 57.0% copper; 42.0% zinc; 1.0% iron. Castings have a tensile strength of about 45,000 pounds per square inch. Rolled or forged bars have a tensile strength of about 60,000 pounds per square inch. The iron is chemically combined by dissolving wrought iron in the molten copper. Tin, manganese, or lead is sometimes introduced into the alloy, to impart special properties to it. Delta metal can be forged at a dark cherry-red heat.

**Duralumin.**—Composition: 3.6% copper; 0.5 silicon; 0.60% iron; 0.4% manganese; 94.9% aluminum. Specific gravity, 2.79. Tensile strength of castings about 35,800 pounds per square inch. It is used in the form of sheets and wire. The tensile strength of sheets is about 76,000 pounds per square inch.

Duralumin. Composition by analysis, Law: 4.06% copper; 0.53% manganese; 0.86% magnesium; 0.40% silicon; 1.55% iron; 92.60% aluminum (by difference).

**Fusible Alloy.**—Charpy gives the most fusible alloy: 52.0% bismuth; 32.0% lead; 16.0% tin. Fusing point, 96° C. (204.8° F.). He calls this the eutectic alloy.

**Newton's Fusible Alloys.** Composition: 50.0% bismuth; 31.25% lead; 18.75% tin. Melting point, 95° C. (203° F.).

**Rose's alloy:** 50.0% bismuth; 28.0% lead; 22.0% tin. Melting point, 100° C. (212° F.).

**Wood's alloy:** 38.46% bismuth; 30.77% lead; 15.38% tin; 15.39% cadmium. Melting point, 71° C. (160° F.).

**Lipowitz's alloy:** 50.0% bismuth; 27.0% lead; 13.0% tin; 10.0% cadmium. Melting point, 60° C. (140° F.).

**Fusible Alloys.** Darcet's formulas: A. 57.14% bismuth; 14.29% lead; 28.57% tin.

B. 59.26% bismuth; 14.82% lead; 25.93% tin.

C. 60.0% bismuth; 13.33% lead; 26.67% tin.

Of these all become more or less soft at 100° C. (212° F.); alloy B becomes softer than either A or C.

D. 57.14% bismuth; 17.85% lead; 25.00% tin, becomes nearly fluid at 100° C. (212° F.).

E. 53.33% bismuth; 20.00% lead; 26.67% tin, becomes liquid at 100° C. (212° F.), but not very fluid.

F. 50.0% bismuth; 25.0% lead; 25.0% tin becomes very liquid at 100° C. (212° F.). The melting point of this alloy is said to be 93° C. (199.4° F.).

**Gear Bronze.**—Hard. Composition: 89.0% copper; 11.0% tin. Tensile strength, about 37,500 pounds per square inch. Elastic limit, about 21,600 pounds. Suitable for worm-wheels with steel worm.

Gear Bronze. Medium hard. Composition: 88.0% copper; 10.0% tin; 2.0% lead. Tensile strength, about 32,500 pounds per square inch. Suitable for worm-wheels with steel worm.

**German Silver.**—An alloy consisting of nickel, copper, and zinc. This alloy has the properties of whiteness, luster, hardness, tenacity, toughness, malleability, and ductility. The proportions of the above metals vary widely, and to these are sometimes added: Tin, iron, cobalt, silver, manganese, aluminum, lead, antimony, magnesium, according to the needs or the fancy of the manufacturer. Hiorns states that founders whose specialty is German silver have agreed that the best alloy for beauty, luster, and working properties is 46.0% copper; 34.0% nickel; 20.0% zinc.

German Silver, Notes on.—The metals most often found in German silver and regarded as impurities are iron, tin, and lead. Iron forms a solid solution with the alloy; it increases the strength, hardness, and elasticity of German silver, and makes it slightly whiter. In general, 1 to 2% of iron does not affect its working; in fact, nearly all commercial castings contain some iron. In mixtures intended for rolling and spinning, iron has been found to be very objectionable. In regard to color, an alloy containing 12.0% nickel with iron is said to be equal to an alloy containing 16.0% nickel in which no iron is present, zinc being the same in each case. To alloy iron with copper and nickel by Hiorns' method: Heat together the best iron wire with copper and nickel in a covered crucible, add zinc to the molten mass, stir vigorously and pour into ingots; the metals will form a perfect alloy and no separation of iron can be detected when the ingot is rolled into a thin sheet and highly polished.

Tin, to the extent of 2 to 4%, is much more injurious to German silver than is iron, the alloy showing brittleness in rolling and a decided yellow cast when polished; there is, therefore, no advantage in adding tin to German silver. Tin does not enter into solid solution in the alloy, but forms a eutectic which renders the metal brittle. For use in ornamental castings, 1 to 2% tin is sometimes used.

Lead, to the extent of 1 to 3%, is sometimes added in castings to facilitate lathe and hand fitting.

Arsenic injures the working qualities of German silver and should never be present.

Cobalt frequently accompanies nickel and alloys readily with it; it exerts no injurious influence in German silver alloys.

**Graphite Bearing Metal.**—Composition by analysis, Dudley: 15.0% tin; 68.0% lead; 17.0% antimony. No graphite present.

**Gun Metal.** Admiralty. Composition: 88.0% copper; 10.0% tin; 2.0% zinc

(maximum). Tensile strength, 31,360 pounds per square inch. Castings must be sound, clean, and free from blow-holes.

Gun Metal. Bearings. Composition: 88.0% copper; 10.0% tin; 2.0% zinc. Tensile strength about 35,000 pounds per square inch. Suitable for heavy pressures and high speeds.

Gun Metal. Cast.—Composition G. United States Navy. 87–89% copper; 9–11% tin; 1–3% zinc; 0.06% iron (maximum); 0.2% lead (maximum). Uses: All composition valves 4 inches in diameter and above; expansion joints, flanged pipe fittings, gear wheels, bolts and nuts, miscellaneous brass castings, all parts where strength is required of brass castings or where subjected to salt water, and for all purposes where no other alloy is specified.

Gun Metal. English.—Composition: 87.0% copper; 8.0% tin; 5.0% zinc. For general engine fittings.

Gun Metal. Good alloy for general use. English.—Composition: 88.0% copper; 8.0% tin; 2.0% zinc; .0% lead. Melts about 950° C. (1742° F.).

**Lead-Bronze Bearing Metal.** Composition: 77.0% copper; 10.5% tin; 12.5% lead. The wear is comparatively low with lead bronze, but the friction is higher than with bronzes containing less lead. A nickel alloy consisting of 64.0% copper; 5.0% tin; 30.0% lead; 1.0% nickel is given by Hiorns as being largely in use, as it allows a much greater proportion of lead with the consequent diminished wear.

**Lumen Bearing Metal.**—Composition: 10.0% copper; 85.0% zinc; 5.0% aluminum.

**Macadamite.**—Composition: 72.0% aluminum; 24.0% zinc; 4.0% copper. This alloy has been used to replace brass where lightness is desirable.

**Magnalium.**—This alloy, by Dr. Ludwig Mach, consists of 100 parts aluminum and 10 to 30 parts of magnesium. It is very light in weight, and can be made hard or soft as desired. It is pure white, takes a higher polish than silver, and is said to have all the merits and none of the defects of pure aluminum. The alloys containing more than 15.0% magnesium at one end of the series or more than 15.0% aluminum at the other are brittle. Magnesium has the power of freeing aluminum from dissolved oxide. The three chief magnalium alloys are termed by the makers X, Y, and Z. X is used for very strong castings, Y for ordinary castings, and Z for rolling and drawing.

X contains 1.76% copper; 1.16% nickel; 1.6% magnesium; and 95.48% aluminum.

Y is similar to X, but contains no nickel and a small quantity of tin and lead.

Z contains 3.15% tin; 0.21% copper; 0.72% lead; 1.58% magnesium; and 94.34% aluminum. Hiorns.

**Magnalium.**—Composition by analysis: 94.5% aluminum; 2.0% zinc; 2.0% copper; 1.0% iron; 0.6% magnesium. Tensile strength (rolled), 20,832 pounds per square inch, with 25% elongation.

**Magnolia Metal.**—Composition by analysis, Dudley: 83.55% lead; 16.45% antimony; with traces of copper, zinc, and iron.

Composition by analysis, R. H. Smith: 78.0% lead; 16.0% antimony; 6.0% tin.

*Note.*—Magnolia metal is a trade name; it is not confined to a single composition.

**Manganese Bronze.**—Composition: For castings, 56.0% copper; 41.0% zinc; 0.9% tin; 1.5% iron; 0.15% manganese; 0.45% aluminum. Specific gravity, 8.39.

For rods, 56.0% copper; 40.6% zinc; 0.9% tin; 0.25% iron; 2.0% manganese; 0.25% aluminum.

Manganese Bronze. Cast.—United States Navy. Composition Mn-c: 56.58% copper; 1.0% tin (maximum); 40–42% zinc; 1.0% iron (maximum); 0.2% lead (maximum); 0.5% aluminum (maximum); 0.3% manganese (maximum); Uses: Propeller, hubs, propeller blades, engine framing, castings requiring great strength, such as main gearing in steering engine; worm-wheels in windlass or turning gear for turrets.

**Manganese Copper.**—Composition: 70.0% copper; 30.0% manganese. Used for electric resistances.

**Manganese-Vanadium Bronze.**—Composition, Law: 58.56% copper; 38.54% zinc; 1.48% aluminum; 0.48% manganese; 1.00% iron; 0.03% vanadium. Tensile strength, about 81,500 pounds per square inch; elastic limit, about 50,600 pounds, elongation, 12% in 2 inches. Reduction of area, 14%.

**Manganin.**—Composition: 84.0% copper; 12.0% nickel; 4.0% manganese. Used for electrical resistance.

**Monel Metal.**—Cast. United States Navy. Composition Mo-c: 60.0% nickel; 6.5% iron (maximum); 0.5% aluminum; 33.0% copper (remainder). Uses: Valve fittings, plumbing fittings, boat fittings, propellers, propeller hubs, blades, engine framing, pump liners, valve seats, shaft nuts and caps, and composition castings requiring great strength.

Monel Metal.—Rolled. Sheets, plates, rods, etc. United States Navy. Composition Mo-r: 60.0% nickel (minimum); 3.5% iron (maximum); 0.5% aluminum (maximum); 36.0% copper (remainder). Uses: Rolled rounds, used principally for propeller-blade bolts, air-pump and condenser bolts, and parts requiring strength and incorrodibility, and pump rods.

**Muntz Metal.**—Composition, English: For plates, 60.0% copper; 40.0% zinc. Specific gravity, 8.40 = 524 pounds per cubic foot = 0.33 pound per cubic inch. Melting point, about 886° C. (1627° F.).

For sheets, 61.0% copper; 39.9% zinc.

For rods, 62.0% copper; 38.0 zinc. This alloy is very ductile and can be forged when hot. It has an ultimate tensile strength of about 49,000 pounds per square inch.

Muntz Metal.—Cast. United States Navy. Composition D-c: 59–62% copper; 38–41% zinc; 0.6% lead (maximum).

Muntz Metal.—United States Navy. Sheets, plates, rods, bars, etc. Non-ferrous metal D-r: 59–62% copper; 38–41% zinc; 0.6% lead (maximum). Tensile strength, 40,000 pounds per square inch. Yield point, 20,000 pounds per square inch. Elongation, 25% in 2 inches.

**Naval Brass.**—Cast. United States Navy. Composition N-c: 60–63% copper; 0.5–1.5% tin; 0.06% iron (maximum); 0.3% lead (maximum); zinc = remainder. Normal, 62 − 1 − 37. Uses (C. and R.): Hatch frames, door frames, scuttle frames; rail and ladder stanchions; brass valves and fittings for ventilation system; belaying pins, brass pipe flanges. (S.E.): Valve handwheels, hand-rail fittings, ornamental and miscellaneous castings, and valves in water chests of condensers.

Naval Brass.—Rolled. Sheets, plates, rods, etc. United States Navy. Composition N-r: 59–63% copper; 0.5–1.5% tin; 0.06% iron (maximum); 0.2% lead (maximum); zinc = remainder. Uses: Bolts, studs, nuts, and turnbuckles, especially if subject to corrosion or salt water, rolled rounds used principally for propeller blade bolts, air pump, and condenser bolts and parts requiring strength and incorrodibility, and pump rods, tube sheets, supporting plates, and shafts for valves in water heads.

**Nickel Silver.**—Composition: 40.0% copper; 30.0% nickel; 30.0% zinc. This mixture is suitable for castings only.

Nickel Silver.—Sheffield. Composition: 57.0% copper; 24.0% nickel; 19.0% zinc.

**Nickelin.**—Composition: 68.0% copper; 32.0% nickel. A copper-nickel alloy for electrical resistances. Another alloy analyzed 55.3% copper; 31.1% nickel; 13.1% zinc.

**Non-Ferrous Metal D-r.**—United States Navy. Muntz metal sheets, plates, rods, bars, etc. Composition: 59–62% copper; 38–41% zinc; 0.6% lead (maximum).

**Phosphor Bronze.**—Castings. United States Navy. Composition P-c:

Grade 1. 85–90% copper; 6–11% tin; 8.44% zinc (remainder); 0.06% iron (maximum); 0.2% lead (maximum); 0.3% phosphorus (maximum).

Grade 2. 78–81% copper; 9–13% tin; 4.3% zinc (remainder); 8–11% lead (maximum); 0.7–1.0% phosphorus (maximum).

Uses, Grade 1: Valve stems and fittings, etc., exposed to the action of salt water; sheathing, gears, and driving or main nuts for steering gears; castings where strength and incorrodibility are required. Grade 2: Gun fittings (ordnance).

Phosphor Bronze.—Rolled or drawn. United States Navy. Composition P-r:

Grade 1. 94–96% copper; 5–4% tin; 0.10% phosphorus (maximum); zinc, iron, or lead, when present as impurities must not exceed 0.10% as a total for the three.

Grade 2. 85–95% copper; 10–5% tin; 4.0% zinc (maximum); 0.06% iron (maximum); 0.2% lead (maximum); 0.15% phosphorus (maximum).

Uses, Grade 1: Rods, pins, spring wire, etc. Grade 2: Pump rods, valve stems, objects exposed to salt water.

Phosphor Bronze.—Dudley's Standard. Composition: 79.7% copper; 10.0% tin; 9.5% lead; 0.8% phosphorus.

Phosphor Bronze.—Pennsylvania Railroad. Composition: 79.7% copper; 10.0% tin; 9.5% lead; 0.8% phosphorus. Rejections will occur if deliveries fail to show between 9.0 and 11.0% tin; 8.0 and 11.0% lead; 0.7 and 1.0% phosphorus.

**Plastic Bronze.**—Composition: 65.0% copper; 5.0% tin; 30.0% lead. The lead does not alloy with the copper but separates out in the form of globules, which ought to be uniformly distributed throughout the mass. In this alloy the soft particles of lead are embedded in the harder matrix of copper and tin; the addition of lead increases the plasticity of the alloy.

**Platinoid.**—Composition: 60.0% copper; 14.0% nickel; 24.0% zinc; 1.0 to 2.0% tungsten. This alloy has high electric resistance, not changing with temperature. Note: Many samples of so-called platinoid failed to show even traces of tungsten on analysis.

**Rheotan.**—Composition: 84.0% copper; 4.0% zinc; 12.0% manganese. Used for electrical resistance.

Rheotan.—Guillett's formula. Composition: 54.0% copper; 25.0% nickel; 17.0% zinc; 4.0% iron.

**Silicon Bronze.**—Composition, Guillemin: 89.0% copper; 9.0% tin; 1.5% zinc; 0.5% lead; silicon, traces. Tensile strength, about 38,000 pounds per square inch with 20% elongation. Cupro-silicon is used in the manufacture of silicon bronze. The hardness and strength of alloys can be increased or decreased at will by increasing or decreasing silicon.

**Solder.**—Aluminum. Composition: 69.0% tin; 26.2% zinc; 2.4 phosphor tin (10.0% P.); 2.4% aluminum. Richards. This solder is said to be capable of being used with a soldering iron, and not to disintegrate after exposure to air.

Solder.—Half and half. United States Navy. To be made from new tin, Straits, Malacca, or Australian, and commercially pure lead. Total tin and lead = 99.8%. Tin between 49 and 51%. Antimony not more than 0.10%; zinc, none.

Solder.—Hard for copper and brass. Composition: 66.67% copper; 33.33% zinc. Flux: Borax.

Other compositions: Good tough brass, 83.33%, and 16.67% zinc. Flux: Borax. A more fusible solder consists of equal parts copper and zinc.

Solder.—Nickel silver. Composition: 47.0% copper; 11.0% nickel; 42.0% zinc.

Solder.—Tinmen's. Composition: 60.0% tin; 40.0% lead. Flux: Rosin or zinc chloride. Fluxing temperature, 334° F. (168° C.).

For fine solder: 66.67% tin; 33.33% lead. Flux: Rosin or zinc chloride. Fluxing temperature, 340° F. (171° C.).

**Spelter Solder.**—United States Navy. Composition A: Long-grain solder. To consist of not less than 52.0% copper, not more than 2.0% lead; not more than 0.1% iron, and the remainder zinc.

B: Gray spelter solder. Quick running. To consist of 49–52% copper; 3–3.5% tin; not more than 0.5% lead, and the remainder zinc.

**Steam Metal.** — Brass. High grade. Composition: 85.0% copper; 5.0% tin; 5.0% zinc; 5.0% lead. Tensile strength, about 30,000 pounds per square inch.

**Sterro Metal.**—Composition: 60.0% copper; 38.0 to 38.5% zinc; and 1.5–2.0% iron. The proportion of iron is found to vary somewhat and tin is sometimes added to the alloy. Baron Rosthorn's analysis of sterro metal indicated 55.04% copper; 42.36% zinc; 0.83% tin; 1.77% iron; this alloy yielded 60,480 pounds per square inch tensile strength for castings; 76,160 pounds for forgings; 85,120 pounds when cold drawn. The presence of iron in this alloy imparts to it a strength equal to that of mild steel. It is recommended as an alloy for sheathing for ships and other objects which are subjected to the continued action of salt water.

**Tobin Bronze.**—Composition: 58.22% copper; 2.30% tin; 39.48% zinc. Specific gravity, 8.379. Weight per cubic inch, 0.302 pounds. Tensile strength, about 60,000

pounds per square inch, with yield point about one-half the tensile strength. Used for bolts, nuts, pump rods, condenser tube plates, etc.

Tobin Bronze.—Composition by analysis, Dudley: 59.0% copper; 2.1% tin; 0.3% lead; 38.4% zinc; 0.1% iron.

**Torpedo Bronze.**—United States Navy. Composition: 59–62% copper; 0.5–1.5% tin; 0.3% lead (maximum); 0.1% iron (maximum); the remainder zinc. To contain no aluminum. Tests: Must stand hammering hot to a fine point and bending cold through 120° with inner radius equal to diameter or thickness of bar.

**Valve Bronze.**—United States Navy. Composition M: 87.0% copper; 7.0% tin; 4.94% zinc (remainder); 0.06% iron (maximum); 1.0% lead (maximum). Uses: Valves below 4 inches for steam and general purposes for which the material is not otherwise specified, manifolds and cocks, relief valves, composition lug sockets, and pad eyes not requiring special strength, hose couplings, and fittings.

**Vanadium Bronze.**—Cast. United States Navy. Composition Vn-c: 61.0% copper (minimum); 38.0% zinc (maximum); remainder not to exceed 1.0% tin, with lead, bismuth, aluminum, vanadium, and nickel. Tensile strength, 55,000 pounds per square inch as a minimum.

**White Brass.**—Alloys known as white brass are, in general, German silver alloys. The composition of German silver varies widely in its proportions of the metals copper, zinc, and nickel. Nickel will vary from 18 to 25%; zinc from 20 to 30%; the remainder copper. Alloys of copper and zinc containing less than 45.0% copper are no longer yellow; when the percentage of copper is below 40.0%, but above 30.0%, the alloy is white. Nickel whitens as well as strengthens the alloy; it also makes the alloy more non-corrodible than copper and zinc alone. The term white brass should not be confused with white metal anti-friction alloys.

White Brass.—Parsons'. Composition, Campbell: 5.0% copper; 65.0% tin; 30.0% zinc.

Composition, Seaton: 5.6% copper; 17.5% tin; 0.8% antimony; 76.1% zinc.

**White Metal.**—Admiralty. Composition: 7.0% copper; 85.0% tin (minimum); 8.0% antimony (minimum). Where bearing brasses are fitted with white metal, they are to be tinned before being filled.

**White Metal for Bearings.**—Composition, Seaton: A very good white metal is made by mixing 6 parts of tin with 1 of copper, and 6 parts of tin with 1 of antimony, and then adding the two mixtures together.

The exact Admiralty specification is at least 85% tin, and not less than 8% antimony, and about 5% copper; zinc or lead not to be used.

White Metal.—Parsons'. Composition, Seaton: 58.5% tin; 2.0% antimony; 39.5 zinc.

Another alloy: 1.0% copper; 68.0% tin; 30.5% zinc; 0.5% lead.

## NOTES ON BEARING METALS

In a properly adjusted bearing with proper lubrication, the composition of the metal is of little importance so long as it is strong enough to bear the load without being squeezed out, or tough enough without being brittle.

**Compressive Strength.**—All white metal alloys intended for shafts should stand a pressure of 9,000 pounds per square inch, alloys for connecting rods should stand 13,000 pounds per square inch before failing. When a bearing is subjected, while running, to gradually increased load, there will come a point where the friction increases out of all proportion to the previous gradual increase; this is the cutting point, or that at which the metal is said to grip. The harder the surfaces in contact, the less the friction, and the higher the load to produce gripping.

**Durability.**—A metal cannot at once possess a low coefficient of friction and durability to a high degree. Lead is the best metal as regards rate of wear; owing, however, to the tendency of its particles to stick to the shaft it is perhaps the worst with regard to friction resistance.

**Low Temperature of Running.**—In high speeds, where the heat generated may be

considerable, an alloy with low specific heat and high thermal conductivity, such as tin, is preferable to alloys high in lead.

**Wear on Journal.**—White metals do not score the shaft as do other alloys in case of deficient lubrication.

**Corrosion.**—Tin and antimony resist the corrosive action of a lubricant entirely, iron, copper, lead, and zinc being corrodible in the order named, zinc being quite the worst.

**Rigid Bronzes.**—When well-fitted, bronzes run cooler and with less friction than other bearing metals, but they wear most of all. The best alloys of this class for heavy loads are the true bronzes. Both the rate of wear and the hardness of the bronzes increase as the tin increases. The practical limit for tin is about 20%; above this the alloys are too brittle to be safe. Bronzes with over 6% tin consist of a portion high in copper surrounded by a eutectic high in tin. As the tin increases the proportion of the eutectic increases; as this is very hard, the hardness of the alloy also increases. Zinc is often added as a cheapening addition for common bearings, but bearings high in zinc wear badly. Phosphorus used as a deoxidizer in making bronzes results in closer-grained, harder, and more homogeneous castings.

**Plastic White Metals.**—Plasticity should be such as to enable the alloy to mold itself round the shaft, but the alloy must be tough enough to stand the working pressure without deformation. Hardness is necessary to give low frictional resistance. These two properties belong to alloys which consist of hard grains embedded in a plastic matrix; a characteristic of all the best anti-friction alloys. The hard grains in service are slightly in relief, and perform most of the bearing duty with a minimum of frictional resistance.

Lead-antimony alloys are the cheapest white lining metals in use, and quite good enough for many purposes, but their compressive strengths are low. Lead and antimony alloy in all proportions; the eutectic alloy contains 13% antimony, but most alloys have antimony in excess of 13%; when a limit of about 25% is reached the alloy becomes too brittle for safe use.

**Alloys of Tin, Antimony, and Copper.**—In this class is included the original Babbitt metal, the highest-priced alloy in common use, because of the high content of tin, but these alloys generally give most satisfaction.

**Alloys of Lead, Antimony, and Tin.**—The introduction of tin to lead-antimony alloys modifies the brittleness of the hard antimony grains by the presence in solid solution of a greater or less amount of the antimony-tin compound, which also enters into the antimony of the eutectic matrix, increasing its compressive strength. Their heat-dissipating capacity, determined by the combined effects of specific heat, thermal conductivity, and radiative capacity, is inferior to the high-tin alloys, and should not be recommended for high speeds.

**Alloys of Tin, Zinc, and Antimony.**—A remarkable property of these alloys is their high compressive strengths. They are difficult to cast, as the volatilization of zinc is aggravated in the presence of antimony.

**Deoxidizing Agents.**—Arsenic when not above 1% produces a fine-grained fracture, and freedom from blow-holes; but it does not improve the alloy's wearing properties. Phosphorus, potassium cyanide, and sodium are also used as deoxidizing agents.

**Plastic Bronzes.**—The want of plasticity of the rigid bronzes is a disadvantage; attempts made by Dr. Dudley, of the Pennsylvania Railroad Company, to secure higher plasticity by the introduction of lead were successful up to the extent of 15% of lead; after exhaustive tests these alloys replaced the old rigid bronzes. The lead does not appear to alloy to any extent with the bronze, but to be mechanically held by it, and "forms trails of a plastic substance throughout the metal." —*A. Hague.*

## SECTION 10

# MACHINE DETAILS, PRINCIPALLY THOSE RELATING TO STEAM ENGINES

## KEYWAYS AND KEYS

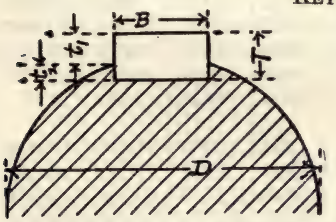
One function of a key is to secure a simultaneous rotative movement of a shaft and the piece keyed to it. The working stresses upon a key sunk into both shaft and hub tend to shearing, there being little or no tendency to axial movement. A key by its breadth and length presents an area of metal between the driving and driven parts, and must be sufficiently large to easily resist the shearing stress. It is important that a sunk key shall completely fill the keyway at its sides to properly resist this shearing effort. The taper of a key should be employed only for fixing the key in place, and not in wedging the shaft and hub apart.

The taper of a key is allowed for on its upper side only; the bottom of keyway is always parallel to the axis of the shaft. The thickness of a tapered key is that of the small end to which the allowance for taper is added. The usual taper for keys is $\frac{1}{8}$ inch per foot.

Key forgings should be of steel. The tensile strength of rolled machinery steel in medium and small sizes will vary from 60,000 to 70,000 pounds per square inch. Keys may, therefore, be considered to be as hard or harder than the shaft, and of course much harder than the cast iron hub into which the key is to be fitted. Steel keys have a safe working strength of 7,500 lbs. per square inch of shearing section.

**Proportions**.—The proportions for sunk keys as formulated by Unwin are in almost universal use in this country; these are given in the accompanying table together with all necessary working dimensions for keys and keyways suitable for shafts from 1 to 12 inches in diameter.

### Keyways and Sunk Keys




Unwin's formula:

$$B = .25D + .125 \text{ inch}$$
$$T = .5B$$
$$t_1 = \text{depth of keyway in hub} = .3B$$
$$t_2 = \text{depth of keyway in shaft} = .2B$$

| Shaft Diam. D | B | T | $t_1$ | $t_2$ | Area of Key | Shearing Resistance of Key per Inch of Length, for Working Values per Square Inch of 6000 Pounds | 7500 Pounds | 10,000 Pounds |
|---|---|---|---|---|---|---|---|---|
| 1 | .375 = $\frac{3}{8}$ | .188 = $\frac{3}{16}$ | .113 | .075 | .0703 | 2250 | 2812 | 3750 |
| $1\frac{1}{8}$ | .406 = $\frac{13}{32}$ | .203 = $\frac{13}{64}$ | .122 | .081 | .0825 | 2438 | 3047 | 4063 |
| $1\frac{1}{4}$ | .438 = $\frac{7}{16}$ | .219 = $\frac{7}{32}$ | .131 | .088 | .0957 | 2625 | 3281 | 4375 |
| $1\frac{3}{8}$ | .469 = $\frac{15}{32}$ | .234 = $\frac{15}{64}$ | .141 | .094 | .1099 | 2813 | 3516 | 4688 |
| $1\frac{1}{2}$ | .500 = $\frac{1}{2}$ | .250 = $\frac{1}{4}$ | .150 | .100 | .1250 | 3000 | 3750 | 5000 |

KEYWAYS AND SUNK KEYS—*Continued*

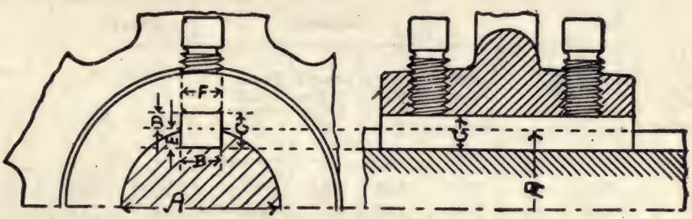
| Shaft Diam. D | B | T | $t_1$ | $t_2$ | Area of Key | Shearing Resistance of Key per Inch of Length, for Working Values per Square Inch of | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 6000 Pounds | 7500 Pounds | 10,000 Pounds |
| 1⅝ | .531 = $\frac{17}{32}$ | .266 = $\frac{17}{64}$ | .159 | .106 | .1411 | 3188 | 3985 | 5313 |
| 1¾ | .563 = $\frac{9}{16}$ | .281 = $\frac{9}{32}$ | .169 | .113 | .1670 | 3375 | 4219 | 5625 |
| 1⅞ | .594 = $\frac{19}{32}$ | .297 = $\frac{19}{64}$ | .178 | .119 | .1763 | 3563 | 4454 | 5938 |
| 2 | .625 = ⅝ | .313 = $\frac{5}{16}$ | .188 | .125 | .1953 | 3750 | 4688 | 6250 |
| 2⅛ | .656 = $\frac{21}{32}$ | .328 = $\frac{21}{64}$ | .197 | .131 | .2153 | 3938 | 4922 | 6563 |
| 2¼ | .688 = $\frac{11}{16}$ | .344 = $\frac{11}{32}$ | .206 | .138 | .2364 | 4125 | 5156 | 6875 |
| 2⅜ | .719 = $\frac{23}{32}$ | .359 = $\frac{23}{64}$ | .216 | .144 | .2583 | 4313 | 5391 | 7188 |
| 2½ | .750 = ¾ | .375 = ⅜ | .225 | .150 | .2813 | 4500 | 5625 | 7500 |
| 2⅝ | .781 = $\frac{25}{32}$ | .391 = $\frac{25}{64}$ | .234 | .156 | .3052 | 4688 | 5860 | 7813 |
| 2¾ | .813 = $\frac{13}{16}$ | .406 = $\frac{13}{32}$ | .244 | .163 | .3301 | 4875 | 6094 | 8125 |
| 2⅞ | .844 = $\frac{27}{32}$ | .422 = $\frac{27}{64}$ | .253 | .169 | .3560 | 5063 | 6329 | 8438 |
| 3 | .875 = ⅞ | .438 = $\frac{7}{16}$ | .263 | .175 | .3828 | 5250 | 6563 | 8750 |
| 3⅛ | .906 = $\frac{29}{32}$ | .453 = $\frac{29}{64}$ | .272 | .181 | .4106 | 5438 | 6797 | 9063 |
| 3¼ | .938 = $\frac{15}{16}$ | .469 = $\frac{15}{32}$ | .281 | .188 | .4395 | 5625 | 7031 | 9375 |
| 3⅜ | .969 = $\frac{31}{32}$ | .484 = $\frac{31}{64}$ | .291 | .194 | .4693 | 5813 | 7266 | 9688 |
| 3½ | 1.000 = 1 | .500 = ½ | .300 | .200 | .5000 | 6000 | 7500 | 10 000 |
| 3⅝ | 1.031 = 1$\frac{1}{32}$ | .516 = $\frac{33}{64}$ | .309 | .206 | .5317 | 6188 | 7735 | 10 313 |
| 3¾ | 1.063 = 1$\frac{1}{16}$ | .531 = $\frac{17}{32}$ | .319 | .213 | .5645 | 6375 | 7969 | 10 625 |
| 3⅞ | 1.094 = 1$\frac{3}{32}$ | .547 = $\frac{35}{64}$ | .328 | .219 | .5982 | 6563 | 8204 | 10 938 |
| 4 | 1.125 = 1⅛ | .563 = $\frac{9}{16}$ | .338 | .225 | .6328 | 6750 | 8438 | 11 250 |
| 4¼ | 1.188 = 1$\frac{3}{16}$ | .594 = $\frac{19}{32}$ | .356 | .238 | .7051 | 7125 | 8906 | 11 875 |
| 4½ | 1.250 = 1¼ | .625 = ⅝ | .375 | .250 | .7813 | 7500 | 9375 | 12 500 |
| 4¾ | 1.313 = 1$\frac{5}{16}$ | .656 = $\frac{21}{32}$ | .394 | .263 | .8614 | 7875 | 9844 | 13 125 |
| 5 | 1.375 = 1⅜ | .688 = $\frac{11}{16}$ | .413 | .275 | .9453 | 8250 | 10 313 | 13 750 |
| 5¼ | 1.438 = 1$\frac{7}{16}$ | .719 = $\frac{23}{32}$ | .431 | .288 | 1.0333 | 8625 | 10 781 | 14 375 |
| 5½ | 1.500 = 1½ | .750 = ¾ | .450 | .300 | 1.1250 | 9000 | 11 250 | 15 000 |
| 5¾ | 1.563 = 1$\frac{9}{16}$ | .781 = $\frac{25}{32}$ | .469 | .313 | 1.2208 | 9375 | 11 719 | 15 625 |
| 6 | 1.625 = 1⅝ | .813 = $\frac{13}{16}$ | .488 | .325 | 1.3203 | 9750 | 12 188 | 16 250 |
| 6¼ | 1.688 = 1$\frac{11}{16}$ | .844 = $\frac{27}{32}$ | .506 | .338 | 1.4239 | 10 125 | 12 656 | 16 875 |
| 6½ | 1.750 = 1¾ | .875 = ⅞ | .525 | .350 | 1.5313 | 10 500 | 13 125 | 17 500 |
| 6¾ | 1.813 = 1$\frac{13}{16}$ | .906 = $\frac{29}{32}$ | .544 | .363 | 1.6427 | 10 875 | 13 594 | 18 125 |
| 7 | 1.875 = 1⅞ | .938 = $\frac{15}{16}$ | .563 | .375 | 1.7578 | 11 250 | 14 063 | 18 750 |
| 7¼ | 1.938 = 1$\frac{15}{16}$ | .969 = $\frac{31}{32}$ | .581 | .388 | 1.8771 | 11 625 | 14 531 | 19 375 |
| 7½ | 2.000 = 2 | 1.000 = 1 | .600 | .400 | 2.0000 | 12 000 | 15 000 | 20 000 |
| 7¾ | 2.063 = 2$\frac{1}{16}$ | 1.031 = 1$\frac{1}{32}$ | .619 | .413 | 2.1271 | 12 375 | 15 469 | 20 625 |
| 8 | 2.125 = 2⅛ | 1.063 = 1$\frac{1}{16}$ | .638 | .425 | 2.2578 | 12 750 | 15 938 | 21 250 |
| 8¼ | 2.188 = 2$\frac{3}{16}$ | 1.094 = 1$\frac{3}{32}$ | .656 | .438 | 2.3927 | 13 125 | 16 406 | 21 875 |
| 8½ | 2.250 = 2¼ | 1.125 = 1⅛ | .675 | .450 | 2.5313 | 13 500 | 16 875 | 22 500 |
| 8¾ | 2.313 = 2$\frac{5}{16}$ | 1.156 = 1$\frac{5}{32}$ | .694 | .463 | 2.6739 | 13 875 | 17 344 | 23 125 |
| 9 | 2.375 = 2⅜ | 1.188 = 1$\frac{3}{16}$ | .713 | .475 | 2.8203 | 14 250 | 17 813 | 23 750 |

KEYWAYS AND SUNK KEYS—*Continued*

| Shaft Diam. D | B | T | $t_1$ | $t_2$ | Area of Key | Shearing Resistance of Key per Inch of Length, for Working Values per Square Inch of 6000 Pounds | 7500 Pounds | 10,000 Pounds |
|---|---|---|---|---|---|---|---|---|
| 9¼ | 2.438 = $2\frac{7}{16}$ | 1.219 = $1\frac{7}{32}$ | .731 | .488 | 2.9708 | 14 625 | 18 281 | 24 375 |
| 9½ | 2.500 = 2½ | 1.250 = 1¼ | .750 | .500 | 3.1250 | 15 000 | 18 750 | 25 000 |
| 9¾ | 2.563 = $2\frac{9}{16}$ | 1.281 = $1\frac{9}{32}$ | .769 | .513 | 3.2833 | 15 375 | 19 219 | 25 625 |
| 10 | 2.625 = 2⅝ | 1.313 = $1\frac{5}{16}$ | .788 | .525 | 3.4453 | 15 750 | 19 688 | 26 250 |
| 10¼ | 2.688 = $2\frac{11}{16}$ | 1.344 = $1\frac{11}{32}$ | .806 | .538 | 3.6115 | 16 125 | 20 156 | 26 875 |
| 10½ | 2.750 = 2¾ | 1.375 = 1⅜ | .825 | .550 | 3.7813 | 16 500 | 20 625 | 27 500 |
| 10¾ | 2.813 = $2\frac{13}{16}$ | 1.406 = $1\frac{13}{32}$ | .844 | .563 | 3.9552 | 16 875 | 21 094 | 28 125 |
| 11 | 2.875 = 2⅞ | 1.438 = $1\frac{7}{16}$ | .863 | .575 | 4.1328 | 17 250 | 21 563 | 28 750 |
| 11¼ | 2.938 = $2\frac{15}{16}$ | 1.469 = $1\frac{15}{32}$ | .881 | .588 | 4.3146 | 17 625 | 22 031 | 29 375 |
| 11½ | 3.000 = 3 | 1.500 = 1½ | .900 | .600 | 4.5000 | 18 000 | 22 500 | 30 000 |
| 11¾ | 3.063 = $3\frac{1}{16}$ | 1.531 = $1\frac{17}{32}$ | .919 | .613 | 4.6896 | 18 375 | 22 969 | 30 625 |
| 12 | 3.125 = 3⅛ | 1.563 = $1\frac{9}{16}$ | .938 | .625 | 4.8828 | 18 750 | 23 438 | 31 250 |

**Length of Key.**—Apart from resistance to crushing, a key should have length enough to hold it securely in place under any conditions of service. Pulley hub proportions are influenced by those of the rim, but in any case the length of hub is seldom less than twice the diameter of shaft; this provides a little more length than is needed to resist crushing of key. Short hubs, for any service, are seldom less than one shaft diameter in length; if a key is proportioned D ÷ 4 + .125 in., the shortest limit of length is reached when the length of key equals the diameter of shaft for which it is proportioned, as above. The proper length closely approximates 1.6 diameter of shaft.

**Square Sunk Key**—Largely used in machine construction in resisting shearing strains only, any tendency to lateral movement being prevented by one or more set screws in the hub, as shown in the illustration. A common proportion for square keys is one-fourth the diameter of the shaft for sizes from 2 to 4 inches, for smaller shafts




D ÷ 4 + .0625 is often used. In general, square keys are simply cut to length from cold drawn polished rods, and used without further preparation, unless it may be case-hardening. Two set screws are shown in hub; except for hubs of unusual length this is not always necessary. The screw should have a flat point and casehardened to prevent distortion of thread.

**Special Keys.**—Key on a flat, Fig. 1, has the same breadth B for shaft diameter A as has a sunk key. The flat should be parallel to the axis of shaft and a little wider than the key. Its thickness C, measured at the small end is one-third its breadth; the taper is commonly one-eighth inch per foot, for which allowance is made in the hub.

If the piece to be keyed is in a confined space, the key should have a gib head to facilitate its withdrawal.

**Saddle Key**—This key, Fig. 2, is wholly included in the hub, no preparation of shaft being necessary for its use. In breadth D it follows the same proportions relative to shaft diameter as for a sunk key. Thickness E, measured at the small end, is one-third its breadth. The usual taper is one-eighth inch per foot, for which a corresponding taper is included in the hub. The under side of key is made concave to fit the

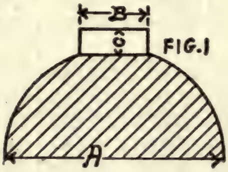



FIG. 1

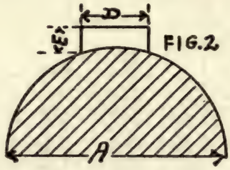



FIG. 2

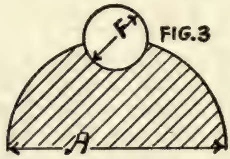
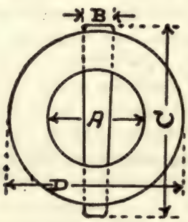



FIG. 3

shaft. To facilitate its removal, the key should have a gib head. As this key lies wholly outside the circumference of shaft, and drives by friction only, it is not well adapted for important power transmission.

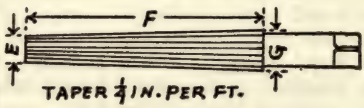
**Round Key.**—This method of fastening, Fig. 3, is sometimes employed instead of a sunk key. For practical reasons it is limited to fastening a hub at the end of a shaft. The diameter of pin may be one quarter the shaft diameter; the hole reamed for either a straight or taper pin. The location of hole is such that one-half the pin is in the hub, the other half in the shaft. A pin key resists working stresses in the same manner as a sunk key, that is, by resistance to shearing. Pin keys are occasionally used in large work, but their use is practically confined to small details in machine construction.

**Taper Pin Key**—In fastening a hub other than at the end of a shaft a pin is made to pass diametrically, or nearly so, through the hub and shaft as shown in sketch. In this case a taper pin is used, the usual taper being ¼ inch per foot. The pin is in double shear.




TAPER PINS AND REAMERS

Commercial Sizes




Taper of pins = ¼ inch per foot

| Pin | | | | Reamer | | | Shaft | | Hub | |
|---|---|---|---|---|---|---|---|---|---|---|
| Trade Number | Diameter Large End B | | Longest Length C Inches | Diam. Small End E | Length Cutting Edge F | Diam. Large End G | Diameter A | | Diameter D | |
| | Dec. | Frac. | | | | | Pin × 3 | Pin × 4 | Pin × 3 | Pin × 4 |
| 1.......... | .172 | 11/64 | 1¼ | .146 | 1¾ | 181 | .516 | .688 | 1.02 | 1.19 |
| 2.......... | .193 | 3/16 | 1½ | .162 | 2 | 204 | .579 | .772 | 1.20 | 1.41 |
| 3.......... | .219 | 7/32 | 1¾ | .183 | 2¼ | 230 | .657 | .876 | 1.41 | 1.63 |
| 4.......... | .250 | ¼ | 2 | .208 | 2½ | 260 | .750 | 1.000 | 1.56 | 1.88 |
| 5.......... | .289 | 19/64 | 2½ | .240 | 3 | 303 | .867 | 1.156 | 1.81 | 2.16 |
| 6.......... | .341 | 11/32 | 3⅛ | .279 | 3⅝ | 355 | 1.023 | 1.364 | 2.09 | 2.49 |
| 7.......... | .409 | 13/32 | 4 | .331 | 4½ | 425 | 1.227 | 1.636 | 2.35 | 2.89 |
| 8.......... | .492 | ½ | 4¾ | .398 | 5¼ | 507 | 1.476 | 1.968 | 2.73 | 3.34 |
| 9.......... | .591 | 19/32 | 5½ | .482 | 6⅛ | 610 | 1.773 | 2.364 | 3.15 | 3.86 |
| 10.......... | .706 | 23/32 | 6 | .581 | 7 | 727 | 2.118 | 2.824 | 3.62 | 4.45 |

Taper pin dimensions coincide with those of the reamer used in fitting the hole. Certain sizes of pins are commonly accepted as standard, the larger sizes of which are tabulated herewith.

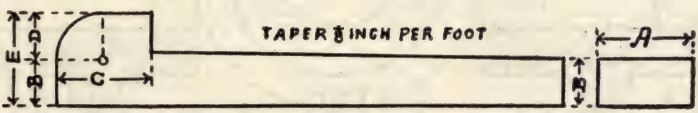
Shaft diameters are given in the table merely to show what diameters result from multiplying the several pin diameters by 3 and 4 respectively. The tabular sizes for shafts are exact multiples of the standard pin diameter, these are to be changed to the nearest common fractional measurement the design may suggest.

The designer must determine how much of the shaft area can be allotted to the pin. Suppose a design calls for a shaft about $1\frac{1}{4}$ inches diameter; the nearest shaft diameter in the table under Pin $\times$ 3 is 1.227, for which a No. 7 pin will be required. In the column Pin $\times$ 4 the choice lies between 1.156 and 1.364 for shaft diameter, the former calls for a No. 5 pin, the latter a No. 6 pin, which size would probably be selected together with an average shaft diameter of $1\frac{1}{4}$ inches.

Shaft diameters as given in the table are subject to increase or decrease in diameter, to conform to the next nearest working unit, suited to the standard parallel reamer used for the hub; thus, 1.227 inches would be increased to 1.25 inches, similarly 1.156 inches would be advanced 1.1875 inches.

Reamer flutes, as well as overall lengths of standard taper pins, are of sufficient length that a moderate increase in shaft diameter is permissible.

**Gib Head Key.**—This form of key is useful in supplying a fixed projection, or an abutment, against which a wedge may be driven in order to loosen a key preparatory to its withdrawal. A table of sizes up to and including 4 inches in breadth is given. The breadth and thickness follow Unwin's proportions for sunk keys; knowing the breadth of a key, suitable working dimensions for a gib head may be taken from the table.




Gib Heads for Keys

| A | B | C | D | E | A | B | C | D | E |
|---|---|---|---|---|---|---|---|---|---|
| $\frac{1}{4}$ | $\frac{3}{16}$ | $\frac{1}{4}$ | $\frac{1}{8}$ | $\frac{5}{16}$ | 2 | 1 | $1\frac{7}{16}$ | $\frac{3}{4}$ | $1\frac{3}{4}$ |
| $\frac{5}{16}$ | $\frac{3}{16}$ | $\frac{5}{16}$ | $\frac{3}{16}$ | $\frac{3}{8}$ | $2\frac{1}{8}$ | $1\frac{1}{16}$ | $1\frac{1}{2}$ | $\frac{3}{4}$ | $1\frac{13}{16}$ |
| $\frac{3}{8}$ | $\frac{3}{16}$ | $\frac{3}{8}$ | $\frac{3}{16}$ | $\frac{3}{8}$ | $2\frac{1}{4}$ | $1\frac{1}{8}$ | $1\frac{1}{2}$ | $\frac{3}{4}$ | $1\frac{7}{8}$ |
| $\frac{7}{16}$ | $\frac{7}{32}$ | $\frac{7}{16}$ | $\frac{7}{32}$ | $\frac{7}{16}$ | $2\frac{3}{8}$ | $1\frac{3}{16}$ | $1\frac{5}{8}$ | $\frac{13}{16}$ | 2 |
| $\frac{1}{2}$ | $\frac{1}{4}$ | $\frac{1}{2}$ | $\frac{1}{4}$ | $\frac{1}{2}$ | $2\frac{1}{2}$ | $1\frac{1}{4}$ | $1\frac{5}{8}$ | $\frac{7}{8}$ | $2\frac{1}{8}$ |
| $\frac{9}{16}$ | $\frac{9}{32}$ | $\frac{9}{16}$ | $\frac{9}{32}$ | $\frac{9}{16}$ | $2\frac{5}{8}$ | $1\frac{5}{16}$ | $1\frac{5}{8}$ | $\frac{7}{8}$ | $2\frac{3}{16}$ |
| $\frac{5}{8}$ | $\frac{5}{16}$ | $\frac{5}{8}$ | $\frac{5}{16}$ | $\frac{5}{8}$ | $2\frac{3}{4}$ | $1\frac{3}{8}$ | $1\frac{3}{4}$ | $\frac{15}{16}$ | $2\frac{5}{16}$ |
| $\frac{11}{16}$ | $\frac{11}{32}$ | $\frac{11}{16}$ | $\frac{11}{32}$ | $\frac{11}{16}$ | $2\frac{7}{8}$ | $1\frac{7}{16}$ | $1\frac{3}{4}$ | 1 | $2\frac{7}{16}$ |
| $\frac{3}{4}$ | $\frac{3}{8}$ | $\frac{3}{4}$ | $\frac{3}{8}$ | $\frac{3}{4}$ | | | | | |
| $\frac{13}{16}$ | $\frac{13}{32}$ | $\frac{13}{16}$ | $\frac{13}{32}$ | $\frac{13}{16}$ | 3 | $1\frac{1}{2}$ | $1\frac{7}{8}$ | 1 | $2\frac{1}{2}$ |
| $\frac{7}{8}$ | $\frac{7}{16}$ | $\frac{7}{8}$ | $\frac{7}{16}$ | $\frac{7}{8}$ | $3\frac{1}{8}$ | $1\frac{9}{16}$ | $1\frac{7}{8}$ | 1 | $2\frac{9}{16}$ |
| $\frac{15}{16}$ | $\frac{15}{32}$ | $\frac{15}{16}$ | $\frac{15}{32}$ | $\frac{15}{16}$ | $3\frac{1}{4}$ | $1\frac{5}{8}$ | $1\frac{7}{8}$ | 1 | $2\frac{5}{8}$ |
| | | | | | $3\frac{3}{8}$ | $1\frac{11}{16}$ | 2 | $1\frac{1}{8}$ | $2\frac{13}{16}$ |
| 1 | $\frac{1}{2}$ | 1 | $\frac{1}{2}$ | 1 | $3\frac{1}{2}$ | $1\frac{3}{4}$ | 2 | $1\frac{1}{8}$ | $2\frac{7}{8}$ |
| $1\frac{1}{8}$ | $\frac{9}{16}$ | $1\frac{1}{16}$ | $\frac{9}{16}$ | $1\frac{1}{8}$ | $3\frac{5}{8}$ | $1\frac{13}{16}$ | $2\frac{1}{8}$ | $1\frac{1}{8}$ | $2\frac{15}{16}$ |
| $1\frac{1}{4}$ | $\frac{5}{8}$ | $1\frac{1}{8}$ | $\frac{9}{16}$ | $1\frac{3}{16}$ | $3\frac{3}{4}$ | $1\frac{7}{8}$ | $2\frac{1}{8}$ | $1\frac{1}{4}$ | $3\frac{1}{8}$ |
| $1\frac{3}{8}$ | $\frac{11}{16}$ | $1\frac{3}{16}$ | $\frac{5}{8}$ | $1\frac{5}{16}$ | $3\frac{7}{8}$ | $1\frac{15}{16}$ | $2\frac{1}{4}$ | $1\frac{1}{4}$ | $3\frac{3}{16}$ |
| $1\frac{1}{2}$ | $\frac{3}{4}$ | $1\frac{1}{4}$ | $\frac{5}{8}$ | $1\frac{3}{8}$ | 4 | 2 | $2\frac{1}{4}$ | $1\frac{1}{4}$ | $3\frac{1}{4}$ |
| $1\frac{5}{8}$ | $\frac{13}{16}$ | $1\frac{1}{4}$ | $\frac{5}{8}$ | $1\frac{7}{16}$ | | | | | |
| $1\frac{3}{4}$ | $\frac{7}{8}$ | $1\frac{5}{16}$ | $\frac{11}{16}$ | $1\frac{9}{16}$ | | | | | |
| $1\frac{7}{8}$ | $\frac{15}{16}$ | $1\frac{3}{8}$ | $\frac{11}{16}$ | $1\frac{5}{8}$ | | | | | |

**Sliding Keys.**—When a rotating hub in a fixed bearing is required to rotate a shaft passing through it, the shaft having an end movement as well, the driving key included in the hub is then provided with gib heads, or other form of fastening, to prevent the key sliding out of place.

A sliding key, such as included in the feed works of a machine tool, has but little work to do, and one key will suffice; but if, as in the case of a large boring machine spindle, it may be required to transmit nearly the whole power of the machine, two keys are recommended, to be placed diametrically opposite each other in the spindle.

For light and medium work the breadth of key may be one-fourth the shaft diameter; the thickness of key following, usually, 0.25 shaft diameter + 0.125 inch.

For heavy work the breadth of key diminishes somewhat, because two keys are commonly employed, the proportionate rate for thickness of key remaining as above.

To increase the surface of key subject to wear, 0.4 of the key may be placed in the hub and 0.6 in the keyway in shaft.

The gib head details for a sliding key will depend upon the clearance at end of traverse. Should the hub have little or no clearance the gib will be included within the hub as in Fig. 2, if plenty of clearance, the ends may then project as in Fig. 3.

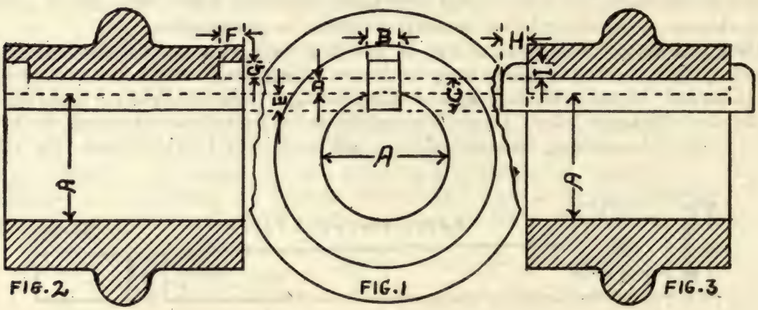



FIG. 2 FIG. 1 FIG. 3

SLIDING KEYS

| A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|
| 1 | 1/4 | 3/8 | .150 | .225 | 1/8 | 1/8 | 3/16 | 1/8 |
| 1 1/4 | 5/16 | 7/16 | .175 | .263 | 1/8 | 1/8 | 3/16 | 1/8 |
| 1 1/2 | 3/8 | 1/2 | .200 | .300 | 3/16 | 3/16 | 1/4 | 3/16 |
| 1 3/4 | 7/16 | 9/16 | .225 | .338 | 3/16 | 3/16 | 1/4 | 3/16 |
| 2 | 1/2 | 5/8 | .250 | .375 | 1/4 | 3/16 | 5/16 | 3/16 |
| 2 1/4 | 9/16 | 11/16 | .275 | .413 | 1/4 | 3/16 | 5/16 | 3/16 |
| 2 1/2 | 5/8 | 3/4 | .300 | .450 | 1/4 | 3/16 | 5/16 | 3/16 |
| 2 3/4 | 11/16 | 13/16 | .325 | .488 | 1/4 | 1/4 | 3/8 | 1/4 |
| 3 | 3/4 | 7/8 | .350 | .525 | 5/16 | 1/4 | 3/8 | 1/4 |
| 3 1/4 | 13/16 | 15/16 | .375 | .563 | 5/16 | 1/4 | 3/8 | 1/4 |
| 3 1/2 | 7/8 | 1 | .400 | .600 | 5/16 | 1/4 | 7/16 | 1/4 |
| 3 3/4 | 15/16 | 1 1/16 | .425 | .638 | 5/16 | 1/4 | 7/16 | 1/4 |
| 4 | 1 | 1 1/8 | .450 | .675 | 3/8 | 5/16 | 7/16 | 5/16 |

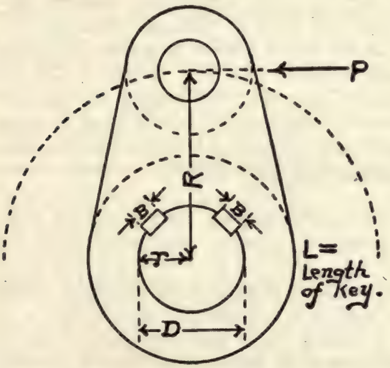
**To facilitate fitting, the hub at F G, Fig. 2, can be notched through; the gib ends at G to extend to outside of hub and finished with it.**

**Maximum Load on Key**—Crank pin pressures in automatic cut-off engines will vary from that due to full boiler pressure at the beginning, to a fourth or less at the end of stroke. In cross compound engines the high pressure steam is confined to one cylinder

the crank and reciprocating mechanism of the low-pressure side is commonly a duplicate of the high-pressure side, the crank keys are somewhat larger than necessary for the work but need not be considered here.

Starting a single or compound engine from a state of rest, the crank pin being at or near half stroke it may, and probably does, receive the maximum load due to full boiler pressure upon piston area which may equal 1,500 pounds per square inch of projected crank pin area, the crank shaft, meanwhile, being at a state of rest. The maximum effort of the steam is transmitted through the crank directly upon the crank shaft keys which, in turn, must resist the shearing effort and permit rotation of shaft. Mean effective pressures cannot be used in determining key proportions.

Keys forged from medium steel have a tensile strength from 65,000 to 70,000 pounds per square inch; 7,500 pounds per square inch of section subject to shearing stress is taken as the working load for a sunk key.



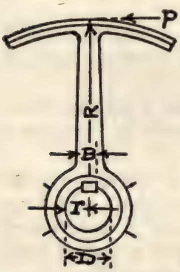

Example. Crank keys for steam engine.
20 inch cylinder = 314.16 sq. in. area.
Steam pressure = 160 lbs. per sq. in.
P = 50,266 pounds = 314.16 × 160.
R = 18 inches.
r = 5 inches.
2 keys. B = $1\frac{3}{4}$ inches.
L = $6\frac{7}{8}$ inches.
D = 10 inches.

Then

$$\frac{P \times R}{r} = \frac{50{,}266 \times 18}{5} = 180{,}958$$

$$2B \times L \times 7500 = 180{,}469$$

The pressure exerted by the steam piston upon the crank pin is 180,958 pounds. The resistance of the two keys in the crank shaft is 180,469 pounds, they thus practically balance each other.




Example. Pulley driving a shaft.
P = 4,000 pounds.
R = 24 inches, radius of pulley.
r = 2 inches, radius of shaft.
B = $1\frac{1}{8}$ inches, key breadth.
L = 6 inches, key length.
D = 4 inches, shaft diameter.

Then

$$\frac{P \times R}{r} = \frac{4{,}000 \times 24}{2} = 48{,}000$$

$$B \times L \times 7500 = 1.125 \times 6 \times 7500 = 50{,}625.$$

In this example there is a margin of 2625 pounds in favor of the key. The breadth of key is by Unwin's formula: $B = \frac{D}{4} + \frac{1}{8}$ inch.

**Keyways for Minor Attachments.**—Keyways in engine shafts are much too large for the needs of minor attachments sometimes carried by it, such as pulleys, gears, eccentrics, etc., transmitting but a fraction of the total power. No general rule can be given for such minor fastenings other than to select a hub suited to the pulley or gear and employ its corresponding size of key for which an additional keyway should be made in the shaft. A small pulley thus placed on an engine shaft would in all probability be made in halves, in which case the small keyway in shaft need not be longer than the pulley hub.

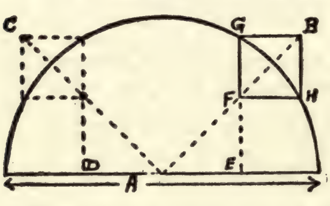
**Double Keys.**—A limit so the breadth of a single key is quickly reached in large shafts transmitting full power. By Unwin's formula the breadth of a single key for a 24-inch shaft would be $6\frac{1}{8}$ inches, its depth $3\frac{1}{16}$ inches. The shearing resistance of a key varies as its breadth; we can, therefore, divide this breadth into two or more keys without loss of strength. Referring to the accompanying table of double keys, a 24-inch shaft would have two keys 4 inches in breadth. Two thicknesses are given for double keys according to the severity of service. For a crank the key thickness would be 3 inches; for a pulley the thickness would be 2 inches. The crank would have its keys placed 90° apart; the pulley would have its keys diametrically opposed, one key in each half of the hub.

The liberal proportions of double as compared with single keys is to favor the exacting conditions under which double keys are commonly used. The stresses upon a crank and shaft are, in general, more severe than those in a pulley or gear so that, for the same breadth of key, its thickness may be increased for the crank connection, thereby presenting a larger area opposing deformation of key and keyway through crushing.

Double keys are commonly set at an angle of 90° when placed in cranks and solid hubs. An incidental advantage, outside the real function of a key, occurs in the 90° keyways in a pulley hub, in making three points of support, thus taking up any lost motion between the shaft and hub, should the bore of pulley be sufficiently large to make a loose fit. Keys and keyways are placed diametrically opposite when employed in split hubs, driving each half separately; the bolts passing through a hub will securely clamp it to the shaft.

**Kennedy Double Keys.**—These keys have been satisfactorily used in rolling mills for the transmission of heavy loads subject to periodical reversal. Key dimensions for any shaft may be found thus:

Draw a semicircle in which the diameter A is the same as that of the shaft for which the key is desired. From its center draw 45° angle lines beyond the circumference as at B and C. Bisect each half diameter as at D and E. From each of these points D and E erect a perpendicular extending to the circumference as at E G. Where the perpendicular crosses the 45° diagonal as at F draw F H parallel to A. Then F H and F G being equal represent two sides of a square key F H B G.




Dimensions for keys suited to shafts from 6 inches to 24 inches diameter are given in table of Double Keys for Cranks and Engine Pulleys.

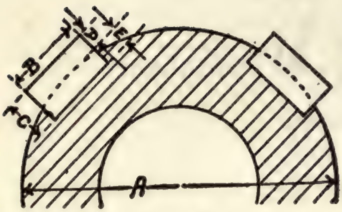
The keyways in the hub and the upper side of the key are tapered $\frac{1}{8}$ inch per foot. The sides of key are parallel and closely fitted into shaft and hub. It will be noted that the key is wholly in compression.

**Peters' Double Key**—This key is designed to have its breadth of bearing located on a radial line in the shaft, and to transmit the rotary motion of the shaft to a diagonally opposite bearing in the hub; or, the reverse, in case motion is to be transmitted through the hub to the shaft. In either case an equal breadth of key is had in both shaft and hub. The working stresses upon the key tend to compression.

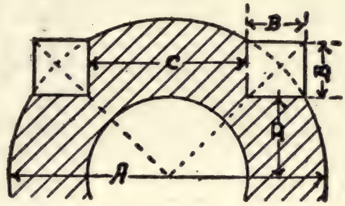
In designing a key of this kind, lay down that portion of hub and shaft in which the keys are to be located, as in the accompanying diagram, in which A is equal to the shaft diameter. From the shaft center, draw two opposite radial lines at an angle of $22\frac{1}{2}$° each, above the horizontal, the complemental angle being 135°. From the circumference of the projected shaft, lay off on one of the diagonal lines the desired breadth of key B, and erect a perpendicular C, intersecting the shaft circumference. The lines B C form two sides of a parallelogram which, when completed, represents the key area. Repeat for the opposite side.

The keyways in both shaft and hub are parallel. Each key, as shown in the diagram, is made up of two halves with central inclined faces; the outer faces of the key are parallel and machined to slide freely into place in the keyways. After the preliminary adjustment each pair of keys is firmly fixed in place, by driving the tapering keys to the desired tension. Any increase of breadth B has the effect of lengthening C, there-

## Double Keys for Cranks and Engine Pulleys



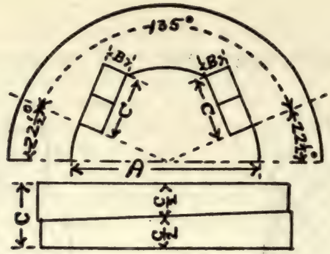

Sunk Key




Kennedy Key

| | Sunk Key | | | | | | | Kennedy | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | For Cranks | | | For Pulleys | | | | | | | |
| Shaft Diam. A | Key Width B | C | Area 1 Key | Shearing Load per Inch on 1 Key at 7500 Lbs per Sq In | C | Area 1 Key | Shearing Load per Inch on 1 Key at 7500 Lbs per Sq In | A | B | C | Area 1 Key | Compression Load per Inch on 1 Key at 7500 Lbs. per Square Inch |
| 6 | 1¼ | ⅞ | 1.09 | 9 375 | ¾ | 0.94 | 9 375 | 6 | 1 1/16 | 3 | 1.13 | 7 968 |
| 6½ | 1 5/16 | 15/16 | 1.23 | 9 844 | ¾ | .98 | 9 844 | 6½ | 1⅛ | 3¼ | 1.27 | 8 441 |
| 7 | 1⅜ | 1 | 1.38 | 10 313 | 13/16 | 1.12 | 10 313 | 7 | 1¼ | 3½ | 1.56 | 9 375 |
| 7½ | 1 7/16 | 1 | 1.44 | 10 781 | 13/16 | 1.17 | 10 781 | 7½ | 1 5/16 | 3¾ | 1.72 | 9 844 |
| 8 | 1½ | 1 1/16 | 1.59 | 11 250 | ⅞ | 1.31 | 11 250 | 8 | 1 7/16 | 4 | 2.07 | 10 781 |
| 8½ | 1 9/16 | 1⅛ | 1.76 | 11 719 | ⅞ | 1.37 | 11 719 | 8½ | 1 9/16 | 4¼ | 2.44 | 11 719 |
| 9 | 1⅝ | 1⅛ | 1.83 | 12 188 | 15/16 | 1.52 | 12 188 | 9 | 1⅝ | 4½ | 2.64 | 12 187 |
| 9½ | 1 11/16 | 1 3/16 | 2.00 | 12 656 | 15/16 | 1.58 | 12 656 | 9½ | 1¾ | 4¾ | 3.06 | 13 125 |
| 10 | 1¾ | 1¼ | 2.19 | 13 125 | 1 | 1.75 | 13 125 | 10 | 1⅞ | 5 | 3.52 | 14 062 |
| 10½ | 1 13/16 | 1 5/16 | 2.38 | 13 594 | 1 | 1.81 | 13 594 | 10½ | 1 15/16 | 5¼ | 3.75 | 14 531 |
| 11 | 1⅞ | 1⅜ | 2.58 | 14 063 | 1 | 1.88 | 14 063 | 11 | 2 | 5½ | 4.00 | 15 000 |
| 11½ | 1 15/16 | 1⅜ | 2.66 | 14 531 | 1 1/16 | 2.06 | 14 531 | 11½ | 2⅛ | 5¾ | 4.52 | 15 937 |
| 12 | 2 | 1 7/16 | 2.88 | 15 000 | 1 1/16 | 2.13 | 15 000 | 12 | 2¼ | 6 | 5.06 | 16 875 |
| 13 | 2⅛ | 1½ | 3.19 | 15 938 | 1⅛ | 2.39 | 15 938 | 13 | 2⅜ | 6½ | 5.64 | 17 812 |
| 14 | 2 5/16 | 1⅝ | 3.76 | 17 344 | 1 3/16 | 2.75 | 17 344 | 14 | 2⅝ | 7 | 6.89 | 19 687 |
| 15 | 2 7/16 | 1 11/16 | 4.11 | 18 281 | 1¼ | 3.05 | 18 281 | 15 | 2¾ | 7½ | 7.56 | 20 625 |
| 16 | 2⅝ | 1 13/16 | 4.76 | 19 688 | 1 5/16 | 3.45 | 19 688 | 16 | 3 | 8 | 9.00 | 22 500 |
| 17 | 2 13/16 | 1 15/16 | 5.45 | 21 094 | 1⅜ | 3.87 | 21 094 | 17 | 3⅛ | 8½ | 9.77 | 23 437 |
| 18 | 3 | 2⅛ | 6.38 | 22 500 | 1½ | 4.50 | 22 500 | 18 | 3⅜ | 9 | 11.39 | 25 312 |
| 19 | 3⅛ | 2¼ | 7.03 | 23 438 | 1 9/16 | 4.88 | 23 438 | 19 | 3½ | 9½ | 12.25 | 26 250 |
| 20 | 3 5/16 | 2⅜ | 7.87 | 24 844 | 1⅝ | 5.38 | 24 844 | 20 | 3¾ | 10 | 14.06 | 28 125 |
| 21 | 3½ | 2 9/16 | 8.97 | 26 250 | 1¾ | 6.13 | 26 250 | 21 | 3⅞ | 10½ | 15.02 | 29 062 |
| 22 | 3⅝ | 2 11/16 | 9.74 | 27 188 | 1 13/16 | 6.57 | 27 188 | 22 | 4⅛ | 11 | 17.02 | 30 937 |
| 23 | 3 13/16 | 2⅞ | 10.96 | 28 594 | 1⅞ | 7.15 | 28 594 | 23 | 4¼ | 11½ | 18.06 | 31 875 |
| 24 | 4 | 3 | 12.00 | 30 000 | 2 | 8.00 | 30 000 | 24 | 4½ | 12 | 20.25 | 33 750 |

fore B must be kept down to a close working limit. As the crushing strength of steel is practically the same as its tensile strength, 7,500 pounds per square inch gives a safe working value to the key.



PETERS' DOUBLE KEY

B = ¼ shaft radius. C = nearest shop measurement. Graphic Determination

| Shaft A | Key B | Key C | Area 1 Key | Compression Load per Inch on 1 Key at 7500 Lbs. per Sq. In. | Shaft A | Key B | Key C | Area 1 Key | Compression Load per Inch on 1 Key at 7500 Lbs. per Square Inch |
|---|---|---|---|---|---|---|---|---|---|
| 4 | ½ | 1 5/16 | 0.66 | 3750 | 7½ | 15/16 | 2½ | 2.34 | 7 031 |
| 4¼ | 17/32 | 1⅜ | .73 | 3985 | 8 | 1 | 2⅝ | 2.63 | 7 500 |
| 4½ | 9/16 | 1½ | .84 | 4219 | 8½ | 1 1/16 | 2 13/16 | 2.99 | 7 969 |
| 4¾ | 19/32 | 1 9/16 | .93 | 4454 | 9 | 1⅛ | 3 | 3.38 | 8 438 |
| 5 | ⅝ | 1⅝ | 1.02 | 4688 | 9½ | 1 3/16 | 3⅛ | 3.71 | 8 906 |
| 5¼ | 21/32 | 1¾ | 1.15 | 4922 | 10 | 1¼ | 3 5/16 | 4.14 | 9 375 |
| 5½ | 11/16 | 1 13/16 | 1.25 | 5156 | 10½ | 1 5/16 | 3½ | 4.59 | 9 844 |
| 5¾ | 23/32 | 1⅞ | 1.35 | 5391 | 11 | 1⅜ | 3⅝ | 4.98 | 10 313 |
| 6 | ¾ | 2 | 1.50 | 5625 | 11½ | 1 7/16 | 3 13/16 | 5.48 | 10 781 |
| 6½ | 13/16 | 2 3/16 | 1.78 | 6094 | 12 | 1½ | 4 | 6.00 | 11 250 |
| 7 | ⅞ | 2 5/16 | 2.02 | 6563 | | | | | |

**Keys for Screw Propellers**—These are always subject to violent changes of load through racing of main engines in a rough sea, not overlooking the frequent and full powered reversals which occur during maneuvers. To meet this service the outboard end of tail shaft is tapered, the propeller boss is bored to fit the tapered shaft, the keys are thicker to resist crushing, and extend the whole length of boss.

Single key proportions by Seaton and Rounthwaite are:
Breadth of key = 0.22 × largest diameter of shaft + 0.25.
Thickness of key = 0.55 × breadth.

The thickness of a single key is limited to about one-eighth the shaft diameter; should this thickness be insufficient, two keys must be used.

The breadth of key is less than in stationary practice by reason of the greater length and consequent area which the key offers in resisting compression or shearing. The breadth of key need not greatly exceed once and a half its total thickness.

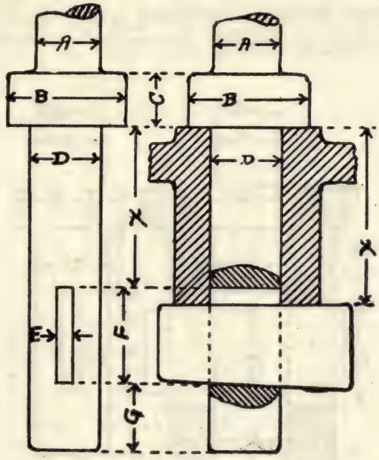
The length of a propeller boss may vary according as the propeller is cast in one piece or whether the boss and blades are cast separately. The former will include all small propellers, especially those of cast iron, for which Seaton and Rounthwaite's rule = 2.7 × diameter of tail shaft. Thus an 8-inch tail shaft would have a taper and boss with key 21.6 inches long. A boss having separate blades will vary between 2.25 and 2.5 diameters in length, averaging the latter figure nearly; in this case, the keyway of the taper end of a 16-inch tail shaft would be 40 inches long.

A propeller shaft of carbon steel will have an elastic limit of about 35,000 pounds

per square inch. If the maximum working stress be fixed at one-half this, a maximum working limit is reached at 17,500 pounds per square inch. When this limit is reached two keys must be used, and these should be placed diametrically opposite each other.

The bearing surface of a key is important in preventing deformation. The shearing of a key of ordinary proportions is quite unlikely to occur. In general, the depth of keyway in a propeller shaft is 0.0625 that of its diameter.

The aggregate area of two keys for a given shaft diameter is greater than for a single




Bolt End with Collar and Cotter

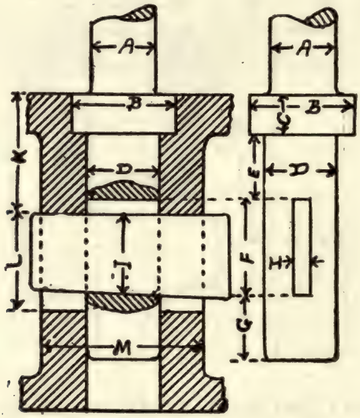
For Rigid Frame Connection

| Bar | | Collar | | Shank | | Slot | | Key |
|---|---|---|---|---|---|---|---|---|
| Diam. A | Area | Diam. B | Thickness C | Diam. D | Length G | Width E | Depth F | H |
| 1 | .785 | $1\frac{5}{8}$ | $\frac{5}{8}$ | $1\frac{1}{8}$ | 1 | $\frac{5}{16}$ | $1\frac{1}{2}$ | $1\frac{1}{4}$ |
| $1\frac{1}{8}$ | .994 | $1\frac{13}{16}$ | $\frac{11}{16}$ | $1\frac{1}{4}$ | $1\frac{1}{16}$ | $\frac{5}{16}$ | $1\frac{11}{16}$ | $1\frac{7}{16}$ |
| $1\frac{1}{4}$ | 1.227 | 2 | $\frac{3}{4}$ | $1\frac{3}{8}$ | $1\frac{1}{8}$ | $\frac{3}{8}$ | $1\frac{7}{8}$ | $1\frac{5}{8}$ |
| $1\frac{3}{8}$ | 1.485 | $2\frac{3}{16}$ | $\frac{13}{16}$ | $1\frac{1}{2}$ | $1\frac{1}{4}$ | $\frac{3}{8}$ | $2\frac{1}{16}$ | $1\frac{13}{16}$ |
| $1\frac{1}{2}$ | 1.767 | $2\frac{3}{8}$ | $\frac{7}{8}$ | $1\frac{11}{16}$ | $1\frac{3}{8}$ | $\frac{7}{16}$ | $2\frac{1}{4}$ | 2 |
| $1\frac{5}{8}$ | 2.074 | $2\frac{9}{16}$ | $\frac{7}{8}$ | $1\frac{13}{16}$ | $1\frac{7}{16}$ | $\frac{7}{16}$ | $2\frac{7}{16}$ | $2\frac{1}{8}$ |
| $1\frac{3}{4}$ | 2.405 | $2\frac{3}{4}$ | $\frac{15}{16}$ | $1\frac{15}{16}$ | $1\frac{1}{2}$ | $\frac{1}{2}$ | $2\frac{5}{8}$ | $2\frac{5}{16}$ |
| $1\frac{7}{8}$ | 2.761 | $2\frac{15}{16}$ | 1 | $2\frac{1}{16}$ | $1\frac{5}{8}$ | $\frac{1}{2}$ | $2\frac{13}{16}$ | $2\frac{1}{2}$ |
| 2 | 3.142 | $3\frac{1}{8}$ | $1\frac{1}{16}$ | $2\frac{1}{4}$ | $1\frac{11}{16}$ | $\frac{9}{16}$ | 3 | $2\frac{11}{16}$ |
| $2\frac{1}{4}$ | 3.976 | $3\frac{1}{2}$ | $1\frac{3}{16}$ | $2\frac{1}{2}$ | $1\frac{7}{8}$ | $\frac{5}{8}$ | $3\frac{3}{8}$ | 3 |
| $2\frac{1}{2}$ | 4.909 | $3\frac{7}{8}$ | $1\frac{5}{16}$ | $2\frac{3}{4}$ | 2 | $\frac{11}{16}$ | $3\frac{3}{4}$ | $3\frac{3}{8}$ |
| $2\frac{3}{4}$ | 5.940 | $4\frac{1}{4}$ | $1\frac{7}{16}$ | $3\frac{1}{16}$ | $2\frac{1}{8}$ | $\frac{3}{4}$ | $4\frac{1}{8}$ | $3\frac{3}{4}$ |
| 3 | 7.069 | $4\frac{5}{8}$ | $1\frac{1}{2}$ | $3\frac{5}{16}$ | $2\frac{5}{16}$ | $\frac{13}{16}$ | $4\frac{1}{2}$ | $4\frac{1}{8}$ |
| $3\frac{1}{4}$ | 8.296 | 5 | $1\frac{5}{8}$ | $3\frac{5}{8}$ | $2\frac{1}{2}$ | $\frac{13}{16}$ | $4\frac{7}{8}$ | $4\frac{7}{16}$ |
| $3\frac{1}{2}$ | 9.621 | $5\frac{3}{8}$ | $1\frac{3}{4}$ | $3\frac{7}{8}$ | $2\frac{11}{16}$ | $\frac{7}{8}$ | $5\frac{1}{4}$ | $4\frac{13}{16}$ |
| $3\frac{3}{4}$ | 11.05 | $5\frac{3}{4}$ | $1\frac{7}{8}$ | $4\frac{1}{4}$ | $2\frac{7}{8}$ | $\frac{15}{16}$ | $5\frac{5}{8}$ | $5\frac{1}{8}$ |
| 4 | 12.57 | $6\frac{1}{8}$ | 2 | $4\frac{1}{2}$ | 3 | 1 | 6 | $5\frac{1}{2}$ |

key, a result of greater thickness, relatively, of double keys over a single one. When the thickness of a double key is determined, its breadth may be one and a half times that thickness.

The central core in a propeller boss is commonly one-third of its length, therefore only two-thirds of the tapered length of a tail shaft is available for driving through the key.

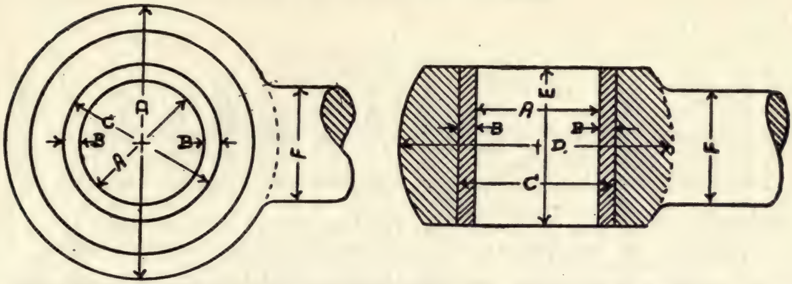
No taper is given the keys used in fastening a propeller boss on the tapered end of a tail shaft. The boss slides over the key or feather (both terms are in use) until taper surfaces are in contact; the boss is followed up by a nut on the outer end of the tail shaft. Taper of tail shaft in the boss of propeller = 1 inch per foot.




Bolt End for Rigid Frame Connection—Countersunk Head and Cotter

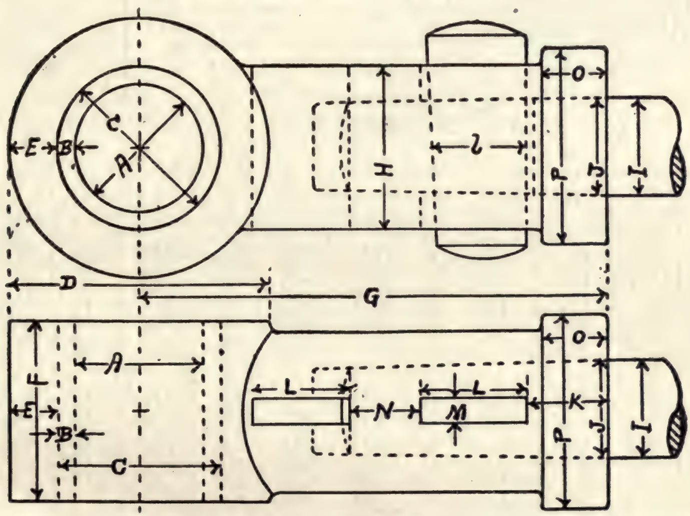
| Bar | | Collar | | Shank | | | | | Key | Frame | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Length | | | | | | | |
| Dia. A | Area | Diam. B | Thickness C | Diam. D | E | F | G | Slot Width H | Key I | K | L | M |
| 1 | .785 | $1\frac{5}{8}$ | $\frac{5}{8}$ | $1\frac{1}{8}$ | 1 | $1\frac{1}{2}$ | 1 | $\frac{5}{16}$ | $1\frac{1}{4}$ | $1\frac{7}{8}$ | $1\frac{1}{2}$ | $2\frac{1}{2}$ |
| $1\frac{1}{8}$ | .994 | $1\frac{13}{16}$ | $\frac{11}{16}$ | $1\frac{1}{4}$ | $1\frac{1}{8}$ | $1\frac{11}{16}$ | $1\frac{1}{16}$ | $\frac{5}{16}$ | $1\frac{7}{16}$ | $2\frac{1}{16}$ | $1\frac{11}{16}$ | $2\frac{3}{4}$ |
| $1\frac{1}{4}$ | 1.227 | 2 | $\frac{3}{4}$ | $1\frac{3}{8}$ | $1\frac{1}{4}$ | $1\frac{7}{8}$ | $1\frac{1}{8}$ | $\frac{3}{8}$ | $1\frac{5}{8}$ | $2\frac{1}{4}$ | $1\frac{7}{8}$ | 3 |
| $1\frac{3}{8}$ | 1.485 | $2\frac{3}{16}$ | $\frac{13}{16}$ | $1\frac{1}{2}$ | $1\frac{3}{8}$ | $2\frac{1}{16}$ | $1\frac{1}{4}$ | $\frac{3}{8}$ | $1\frac{13}{16}$ | $2\frac{7}{16}$ | $2\frac{1}{16}$ | $3\frac{1}{8}$ |
| $1\frac{1}{2}$ | 1.767 | $2\frac{3}{8}$ | $\frac{7}{8}$ | $1\frac{11}{16}$ | $1\frac{1}{2}$ | $2\frac{1}{4}$ | $1\frac{3}{8}$ | $\frac{7}{16}$ | 2 | $2\frac{5}{8}$ | $2\frac{1}{4}$ | $3\frac{3}{8}$ |
| $1\frac{5}{8}$ | 2.074 | $2\frac{9}{16}$ | $\frac{7}{8}$ | $1\frac{13}{16}$ | $1\frac{5}{8}$ | $2\frac{7}{16}$ | $1\frac{7}{16}$ | $\frac{7}{16}$ | $2\frac{1}{8}$ | $2\frac{13}{16}$ | $2\frac{7}{16}$ | $3\frac{1}{2}$ |
| $1\frac{3}{4}$ | 2.405 | $2\frac{3}{4}$ | $\frac{15}{16}$ | $1\frac{15}{16}$ | $1\frac{3}{4}$ | $2\frac{5}{8}$ | $1\frac{1}{2}$ | $\frac{1}{2}$ | $2\frac{5}{16}$ | 3 | $2\frac{5}{8}$ | $3\frac{3}{4}$ |
| $1\frac{7}{8}$ | 2.761 | $2\frac{15}{16}$ | 1 | $2\frac{1}{16}$ | $1\frac{7}{8}$ | $2\frac{13}{16}$ | $1\frac{5}{8}$ | $\frac{1}{2}$ | $2\frac{1}{2}$ | $3\frac{3}{16}$ | $2\frac{13}{16}$ | 4 |
| 2 | 3.142 | $3\frac{1}{8}$ | $1\frac{1}{16}$ | $2\frac{1}{4}$ | 2 | 3 | $1\frac{11}{16}$ | $\frac{9}{16}$ | $2\frac{11}{16}$ | $3\frac{3}{8}$ | 3 | $4\frac{1}{4}$ |
| $2\frac{1}{4}$ | 3.976 | $3\frac{1}{2}$ | $1\frac{3}{16}$ | $2\frac{1}{2}$ | $2\frac{1}{4}$ | $3\frac{3}{8}$ | $1\frac{7}{8}$ | $\frac{5}{8}$ | 3 | $3\frac{13}{16}$ | $3\frac{3}{8}$ | $4\frac{5}{8}$ |
| $2\frac{1}{2}$ | 4.909 | $3\frac{7}{8}$ | $1\frac{5}{16}$ | $2\frac{3}{4}$ | $2\frac{1}{2}$ | $3\frac{3}{4}$ | 2 | $\frac{11}{16}$ | $3\frac{3}{8}$ | $4\frac{3}{16}$ | $3\frac{3}{4}$ | 5 |
| $2\frac{3}{4}$ | 5.940 | $4\frac{1}{4}$ | $1\frac{7}{16}$ | $3\frac{1}{16}$ | $2\frac{3}{4}$ | $4\frac{1}{8}$ | $2\frac{1}{8}$ | $\frac{3}{4}$ | $3\frac{3}{4}$ | $4\frac{9}{16}$ | $4\frac{1}{8}$ | $5\frac{3}{8}$ |
| 3 | 7.069 | $4\frac{5}{8}$ | $1\frac{1}{2}$ | $3\frac{5}{16}$ | 3 | $4\frac{1}{2}$ | $2\frac{5}{16}$ | $\frac{13}{16}$ | $4\frac{1}{8}$ | 5 | $4\frac{1}{2}$ | $5\frac{7}{8}$ |
| $3\frac{1}{4}$ | 8.296 | 5 | $1\frac{5}{8}$ | $3\frac{5}{8}$ | $3\frac{1}{4}$ | $4\frac{7}{8}$ | $2\frac{1}{2}$ | $\frac{13}{16}$ | $4\frac{7}{16}$ | $5\frac{3}{8}$ | $4\frac{7}{8}$ | $6\frac{1}{4}$ |
| $3\frac{1}{2}$ | 9.621 | $5\frac{3}{8}$ | $1\frac{3}{4}$ | $3\frac{7}{8}$ | $3\frac{1}{2}$ | $5\frac{1}{4}$ | $2\frac{11}{16}$ | $\frac{7}{8}$ | $4\frac{13}{16}$ | $5\frac{3}{4}$ | $5\frac{1}{4}$ | $6\frac{5}{8}$ |
| $3\frac{3}{4}$ | 11.05 | $5\frac{3}{4}$ | $1\frac{7}{8}$ | $4\frac{1}{4}$ | $3\frac{3}{4}$ | $5\frac{5}{8}$ | $2\frac{7}{8}$ | $\frac{15}{16}$ | $5\frac{1}{8}$ | $6\frac{1}{8}$ | $5\frac{5}{8}$ | $7\frac{1}{8}$ |
| 4 | 12.57 | $6\frac{1}{8}$ | 2 | $4\frac{1}{2}$ | 4 | 6 | 3 | 1 | $5\frac{1}{2}$ | $6\frac{1}{2}$ | 6 | $7\frac{1}{2}$ |

## Valve Rod End with Bushing




| A | B | C | D | E | F | G | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1/8 | 1 1/4 | 2 1/8 | 1 3/8 | 3/4 | 7/16 | 2 | 1/4 | 2 1/2 | 4 | 2 3/8 | 1 3/8 | 3/4 |
| 1 1/8 | 1/8 | 1 3/8 | 2 3/8 | 1 1/2 | 13/16 | 1/2 | 2 1/8 | 1/4 | 2 5/8 | 4 1/4 | 2 1/2 | 1 7/16 | 13/16 |
| 1 1/4 | 1/8 | 1 1/2 | 2 1/2 | 1 5/8 | 7/8 | 1/2 | 2 1/4 | 1/4 | 2 3/4 | 4 1/2 | 2 5/8 | 1 1/2 | 7/8 |
| 1 3/8 | 1/8 | 1 5/8 | 2 3/4 | 1 3/4 | 1 | 9/16 | 2 3/8 | 1/4 | 2 7/8 | 4 3/4 | 2 3/4 | 1 5/8 | 15/16 |
| 1 1/2 | 3/16 | 1 7/8 | 3 1/8 | 1 7/8 | 1 1/16 | 5/8 | 2 1/2 | 1/4 | 3 | 4 7/8 | 2 7/8 | 1 11/16 | 15/16 |
| 1 5/8 | 3/16 | 2 | 3 3/8 | 2 | 1 1/8 | 11/16 | 2 5/8 | 5/16 | 3 1/4 | 5 1/4 | 3 | 1 3/4 | 1 |
| 1 3/4 | 3/16 | 2 1/8 | 3 1/2 | 2 1/8 | 1 3/16 | 11/16 | 2 3/4 | 5/16 | 3 3/8 | 5 1/2 | 3 1/8 | 1 13/16 | 1 1/16 |
| 1 7/8 | 3/16 | 2 1/4 | 3 3/4 | 2 1/4 | 1 1/4 | 3/4 | 3 | 5/16 | 3 5/8 | 5 7/8 | 3 1/2 | 2 | 1 1/8 |

## Valve Rod End with Coupling



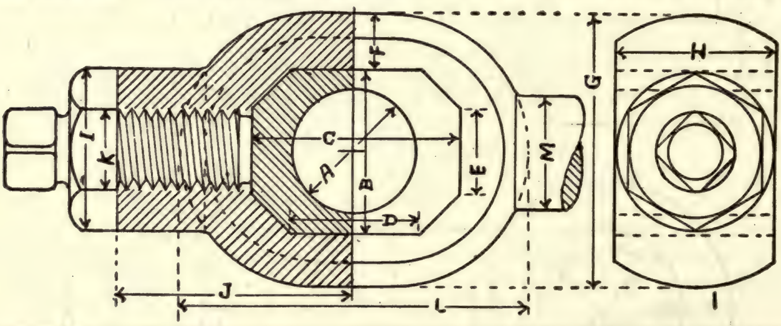

| A | B | C | D | E | F | G | g | H | I | J | K | L | l | M | N | O | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1/8 | 1 1/4 | 2 | 3/8 | 1 3/8 | 3 3/4 | 2 3/16 | 1 1/4 | 3/4 | 3/4 | 5/8 | 13/16 | 3/4 | 3/16 | 5/8 | 1/2 | 1 1/2 |
| 1 1/8 | 1/8 | 1 3/8 | 2 1/8 | 3/8 | 1 1/2 | 4 1/8 | 2 3/8 | 1 3/8 | 13/16 | 13/16 | 11/16 | 7/8 | 13/16 | 3/16 | 11/16 | 9/16 | 1 5/8 |
| 1 1/4 | 1/8 | 1 1/2 | 2 3/8 | 7/16 | 1 5/8 | 4 1/2 | 2 9/16 | 1 1/2 | 7/8 | 7/8 | 3/4 | 15/16 | 7/8 | 1/4 | 3/4 | 5/8 | 1 3/4 |
| 1 3/8 | 1/8 | 1 5/8 | 2 5/8 | 1/2 | 1 3/4 | 4 7/8 | 2 3/4 | 1 9/16 | 1 | 1 | 13/16 | 1 | 15/16 | 1/4 | 13/16 | 5/8 | 1 7/8 |
| 1 1/2 | 3/16 | 1 7/8 | 2 7/8 | 1/2 | 1 7/8 | 5 1/4 | 2 15/16 | 1 11/16 | 1 1/16 | 1 1/16 | 7/8 | 1 1/16 | 1 | 1/4 | 13/16 | 11/16 | 2 |

## Valve Rod End with Coupling—(*Continued*)

| A | B | C | D | E | F | G | g | H | I | J | K | L | l | M | N | O | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 5/8 | 3/16 | 2 | 3 1/8 | 9/16 | 2 | 5 5/8 | 3 1/8 | 1 13/16 | 1 1/8 | 1 1/8 | 1 | 1 1/8 | 1 1/16 | 1/4 | 7/8 | 3/4 | 2 1/8 |
| 1 3/4 | 3/16 | 2 1/8 | 3 3/8 | 5/8 | 2 1/8 | 6 | 3 15/16 | 1 15/16 | 1 1/4 | 1 3/16 | 1 1/16 | 1 3/16 | 1 1/16 | 5/16 | 15/16 | 13/16 | 2 1/4 |
| 1 7/8 | 3/16 | 2 1/4 | 3 1/2 | 5/8 | 2 1/4 | 6 3/8 | 3 1/2 | 2 | 1 5/16 | 1 1/4 | 1 1/8 | 1 1/4 | 1 1/8 | 5/16 | 1 | 13/16 | 2 3/8 |
| 2 | 3/16 | 2 3/8 | 3 3/4 | 11/16 | 2 3/8 | 6 3/4 | 3 11/16 | 2 1/8 | 1 3/8 | 1 5/16 | 1 3/16 | 1 5/16 | 1 3/16 | 5/16 | 1 1/16 | 7/8 | 2 1/2 |
| 2 1/8 | 3/16 | 2 1/2 | 4 | 3/4 | 2 1/2 | 7 1/8 | 3 7/8 | 2 1/4 | 1 7/16 | 1 3/8 | 1 1/4 | 1 3/8 | 1 1/4 | 5/16 | 1 1/8 | 15/16 | 2 5/8 |
| 2 1/4 | 1/4 | 2 3/4 | 4 1/4 | 3/4 | 2 5/8 | 7 1/2 | 4 1/16 | 2 3/8 | 1 1/2 | 1 7/16 | 1 5/16 | 1 7/16 | 1 5/16 | 3/8 | 1 3/16 | 1 | 2 3/4 |
| 2 3/8 | 1/4 | 2 7/8 | 4 1/2 | 13/16 | 2 3/4 | 7 3/4 | 4 1/4 | 2 1/2 | 1 5/8 | 1 1/2 | 1 3/8 | 1 1/2 | 1 3/8 | 3/8 | 1 1/4 | 1 | 2 7/8 |
| 2 1/2 | 1/4 | 3 | 4 3/4 | 7/8 | 2 7/8 | 8 1/8 | 4 7/16 | 2 9/16 | 1 3/4 | 1 5/8 | 1 7/16 | 1 9/16 | 1 3/8 | 3/8 | 1 5/16 | 1 1/16 | 3 |
| 2 5/8 | 1/4 | 3 1/8 | 4 7/8 | 7/8 | 3 | 8 1/2 | 4 5/8 | 2 11/16 | 1 13/16 | 1 11/16 | 1 1/2 | 1 9/16 | 1 7/16 | 3/8 | 1 5/16 | 1 1/8 | 3 1/8 |
| 2 3/4 | 1/4 | 3 1/4 | 5 1/8 | 15/16 | 3 1/8 | 8 7/8 | 4 3/4 | 2 13/16 | 1 7/8 | 1 3/4 | 1 5/8 | 1 5/8 | 1 1/2 | 7/16 | 1 3/8 | 1 3/16 | 3 1/4 |
| 2 7/8 | 1/4 | 3 3/8 | 5 3/8 | 1 | 3 1/4 | 9 1/4 | 4 15/16 | 2 7/8 | 1 15/16 | 1 13/16 | 1 11/16 | 1 11/16 | 1 9/16 | 7/16 | 1 7/16 | 1 3/16 | 3 3/8 |
| 3 | 5/16 | 3 5/8 | 5 5/8 | 1 | 3 1/2 | 9 5/8 | 5 1/8 | 3 | 2 | 1 7/8 | 1 3/4 | 1 3/4 | 1 5/8 | 7/16 | 1 1/2 | 1 1/4 | 3 1/2 |

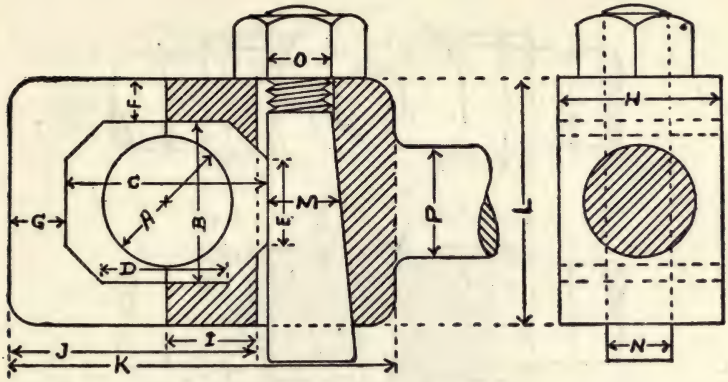
**Valve rod socket and key taper ½ in. per foot.** $g = K + L + N + 0.125$.

## Valve Rod End. Gun Metal Boxes with Set Screw Adjustment and Lock Nut




| A | B | C | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 1/4 | 1 5/8 | 1 | 5/8 | 7/16 | 2 1/8 | 1 3/8 | 1 5/16 | 1 3/4 | 5/8 | 2 3/4 | 3/4 |
| 1 1/8 | 1 5/16 | 1 3/4 | 1 1/8 | 11/16 | 1/2 | 2 5/16 | 1 1/2 | 1 5/16 | 1 7/8 | 5/8 | 3 | 13/16 |
| 1 1/4 | 1 7/16 | 2 | 1 1/4 | 13/16 | 1/2 | 2 7/16 | 1 5/8 | 1 5/16 | 2 | 5/8 | 3 1/4 | 7/8 |
| 1 3/8 | 1 5/8 | 2 1/8 | 1 3/8 | 7/8 | 9/16 | 2 3/4 | 1 3/4 | 1 1/2 | 2 3/16 | 3/4 | 3 1/2 | 1 |
| 1 1/2 | 1 3/4 | 2 1/4 | 1 1/2 | 1 | 5/8 | 3 | 1 7/8 | 1 1/2 | 2 5/16 | 3/4 | 3 3/4 | 1 1/16 |
| 1 5/8 | 1 7/8 | 2 1/2 | 1 5/8 | 1 1/16 | 11/16 | 3 1/4 | 2 | 1 1/2 | 2 1/2 | 3/4 | 4 | 1 1/8 |
| 1 3/4 | 2 | 2 5/8 | 1 3/4 | 1 1/8 | 11/16 | 3 3/8 | 2 1/8 | 1 3/4 | 2 5/8 | 7/8 | 4 1/4 | 1 3/16 |
| 1 7/8 | 2 1/8 | 2 3/4 | 1 3/4 | 1 1/4 | 3/4 | 3 5/8 | 2 1/4 | 1 3/4 | 2 3/4 | 7/8 | 4 1/2 | 1 1/4 |
| 2 | 2 5/16 | 2 7/8 | 2 | 1 5/16 | 3/4 | 3 13/16 | 2 3/8 | 1 3/4 | 2 7/8 | 7/8 | 4 3/4 | 1 3/8 |
| 2 1/8 | 2 7/16 | 3 1/8 | 2 | 1 7/16 | 13/16 | 4 1/16 | 2 1/2 | 2 | 3 | 1 | 5 | 1 7/16 |
| 2 1/4 | 2 9/16 | 3 1/4 | 2 1/8 | 1 1/2 | 7/8 | 4 5/16 | 2 5/8 | 2 | 3 1/8 | 1 | 5 1/4 | 1 1/2 |
| 2 3/8 | 2 3/4 | 3 3/8 | 2 1/4 | 1 9/16 | 15/16 | 4 5/8 | 2 3/4 | 2 | 3 5/16 | 1 | 5 1/2 | 1 5/8 |
| 2 1/2 | 2 13/16 | 3 5/8 | 2 3/8 | 1 11/16 | 15/16 | 4 11/16 | 2 7/8 | 2 1/4 | 3 7/16 | 1 1/8 | 5 3/4 | 1 11/16 |
| 2 5/8 | 3 | 3 3/4 | 2 1/2 | 1 3/4 | 1 | 5 | 3 | 2 1/4 | 3 9/16 | 1 1/8 | 6 | 1 3/4 |
| 2 3/4 | 3 1/8 | 3 7/8 | 2 5/8 | 1 7/8 | 1 1/16 | 5 1/4 | 3 1/8 | 2 1/4 | 3 3/4 | 1 1/8 | 6 1/4 | 1 13/16 |
| 2 7/8 | 3 1/4 | 4 1/8 | 2 3/4 | 1 15/16 | 1 1/16 | 5 3/8 | 3 1/4 | 2 1/2 | 3 7/8 | 1 1/4 | 6 1/2 | 1 7/8 |
| 3 | 3 3/8 | 4 1/4 | 2 7/8 | 2 | 1 1/8 | 5 5/8 | 3 1/2 | 2 1/2 | 4 | 1 1/4 | 6 3/4 | 2 |

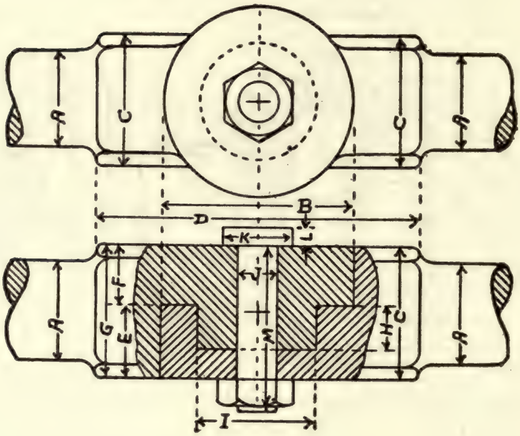
## Valve Rod End. Gun Metal Boxes with Key Adjustment




| A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 1/4 | 1 5/8 | 1 | 5/8 | 1/4 | 3/8 | 1 3/8 | 3/4 | 1 15/16 | 3 | 1 3/4 | 1 3/4 | 1/2 | 1/2 | 3/4 |
| 1 1/8 | 1 5/16 | 1 3/4 | 1 1/8 | 11/16 | 1/4 | 3/8 | 1 1/2 | 13/16 | 2 1/16 | 3 1/8 | 1 13/16 | 5/8 | 1/2 | 1/2 | 13/16 |
| 1 1/4 | 1 7/16 | 2 | 1 1/4 | 13/16 | 5/16 | 7/16 | 1 5/8 | 7/8 | 2 5/16 | 3 1/2 | 2 1/16 | 5/8 | 1/2 | 1/2 | 7/8 |
| 1 3/8 | 1 5/8 | 2 1/8 | 1 3/8 | 7/8 | 3/8 | 1/2 | 1 3/4 | 15/16 | 2 1/2 | 3 13/16 | 2 3/8 | 11/16 | 9/16 | 9/16 | 1 |
| 1 1/2 | 1 3/4 | 2 1/4 | 1 1/2 | 1 | 3/8 | 1/2 | 1 7/8 | 1 1/16 | 2 11/16 | 3 15/16 | 2 1/2 | 11/16 | 9/16 | 9/16 | 1 1/16 |
| 1 5/8 | 1 7/8 | 2 1/2 | 1 5/8 | 1 1/16 | 3/8 | 9/16 | 2 | 1 1/8 | 2 15/16 | 4 3/8 | 2 5/8 | 3/4 | 5/8 | 5/8 | 1 1/8 |
| 1 3/4 | 2 | 2 5/8 | 1 3/4 | 1 1/8 | 7/16 | 5/8 | 2 1/8 | 1 3/16 | 3 1/8 | 4 5/8 | 2 7/8 | 3/4 | 5/8 | 5/8 | 1 3/16 |
| 1 7/8 | 2 1/8 | 2 3/4 | 1 3/4 | 1 1/4 | 7/16 | 5/8 | 2 1/4 | 1 1/4 | 3 1/4 | 4 13/16 | 3 | 13/16 | 5/8 | 5/8 | 1 1/4 |
| 2 | 2 5/16 | 2 7/8 | 2 | 1 5/16 | 1/2 | 11/16 | 2 3/8 | 1 5/16 | 3 7/16 | 5 1/16 | 3 5/16 | 13/16 | 11/16 | 5/8 | 1 3/8 |
| 2 1/8 | 2 7/16 | 3 1/8 | 2 | 1 7/16 | 1/2 | 11/16 | 2 1/2 | 1 7/16 | 3 11/16 | 5 3/8 | 3 7/16 | 7/8 | 11/16 | 5/8 | 1 7/16 |
| 2 1/4 | 2 9/16 | 3 1/4 | 2 1/8 | 1 1/2 | 9/16 | 3/4 | 2 5/8 | 1 1/2 | 3 7/8 | 5 5/8 | 3 11/16 | 7/8 | 3/4 | 3/4 | 1 1/2 |
| 2 3/8 | 2 3/4 | 3 3/8 | 2 1/4 | 1 9/16 | 9/16 | 13/16 | 2 3/4 | 1 9/16 | 4 1/16 | 5 15/16 | 3 7/8 | 15/16 | 3/4 | 3/4 | 1 5/8 |
| 2 1/2 | 2 13/16 | 3 5/8 | 2 3/8 | 1 11/16 | 5/8 | 13/16 | 2 7/8 | 1 5/8 | 4 1/4 | 6 1/4 | 4 1/16 | 1 | 3/4 | 3/4 | 1 11/16 |
| 2 5/8 | 3 | 3 3/4 | 2 1/2 | 1 3/4 | 5/8 | 7/8 | 3 | 1 3/4 | 4 1/2 | 6 1/2 | 4 1/4 | 1 | 13/16 | 3/4 | 1 3/4 |
| 2 3/4 | 3 1/8 | 3 7/8 | 2 5/8 | 1 7/8 | 11/16 | 15/16 | 3 1/8 | 1 13/16 | 4 11/16 | 6 13/16 | 4 1/2 | 1 1/16 | 13/16 | 3/4 | 1 13/16 |
| 2 7/8 | 3 1/4 | 4 1/8 | 2 3/4 | 1 15/16 | 3/4 | 15/16 | 3 1/4 | 1 7/8 | 4 7/8 | 7 1/16 | 4 3/4 | 1 1/16 | 7/8 | 7/8 | 1 7/8 |
| 3 | 3 3/8 | 4 1/4 | 2 7/8 | 2 | 3/4 | 1 | 3 1/2 | 2 | 5 1/8 | 7 3/8 | 4 7/8 | 1 1/8 | 7/8 | 7/8 | 2 |

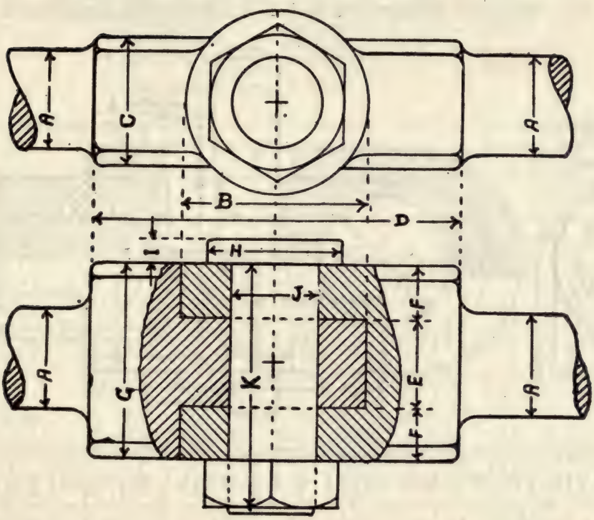
Key tapers 1 in. per foot.

## Valve Rod Knuckle




| A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1/2 | 1 1/8 | 3/4 | 2 1/4 | 7/16 | 5/16 | 3/4 | 1/4 | 11/16 | 5/16 | 9/16 | 1/8 | 15/16 | 1/16 |
| 5/8 | 1 3/8 | 7/8 | 2 5/8 | 1/2 | 3/8 | 7/8 | 1/4 | 7/8 | 3/8 | 5/8 | 1/8 | 1 1/8 | 1/16 |
| 3/4 | 1 9/16 | 1 1/16 | 3 | 5/8 | 7/16 | 1 1/16 | 5/16 | 1 | 7/16 | 3/4 | 3/16 | 1 5/16 | 1/16 |
| 7/8 | 1 13/16 | 1 3/16 | 3 1/4 | 11/16 | 1/2 | 1 3/16 | 7/16 | 1 3/16 | 1/2 | 13/16 | 3/16 | 1 7/16 | 1/16 |
| 1 | 2 | 1 3/8 | 3 5/8 | 3/4 | 5/8 | 1 3/8 | 1/2 | 1 5/16 | 9/16 | 15/16 | 3/16 | 1 11/16 | 1/8 |
| 1 1/8 | 2 1/4 | 1 1/2 | 4 | 13/16 | 11/16 | 1 1/2 | 1/2 | 1 1/2 | 5/8 | 1 | 3/16 | 1 13/16 | 1/8 |
| 1 1/4 | 2 7/16 | 1 5/8 | 4 1/4 | 7/8 | 3/4 | 1 5/8 | 1/2 | 1 9/16 | 5/8 | 1 | 3/16 | 1 15/16 | 1/8 |
| 1 3/8 | 2 5/8 | 1 3/4 | 4 5/8 | 1 | 3/4 | 1 3/4 | 1/2 | 1 11/16 | 5/8 | 1 | 3/16 | 2 1/16 | 1/8 |
| 1 1/2 | 2 3/4 | 1 15/16 | 4 7/8 | 1 1/16 | 7/8 | 1 15/16 | 11/16 | 1 3/4 | 5/8 | 1 | 1/4 | 2 1/4 | 3/16 |
| 1 5/8 | 3 | 2 1/16 | 5 1/8 | 1 1/8 | 15/16 | 2 1/16 | 11/16 | 1 7/8 | 5/8 | 1 | 1/4 | 2 3/8 | 3/16 |
| 1 3/4 | 3 1/8 | 2 1/4 | 5 1/2 | 1 1/4 | 1 | 2 1/4 | 3/4 | 1 15/16 | 3/4 | 1 3/16 | 1/4 | 2 5/8 | 3/16 |
| 1 7/8 | 3 5/16 | 2 3/8 | 5 3/4 | 1 5/16 | 1 1/16 | 2 3/8 | 7/8 | 2 | 3/4 | 1 3/16 | 5/16 | 2 3/4 | 3/16 |
| 2 | 3 1/2 | 2 1/2 | 6 | 1 3/8 | 1 1/8 | 2 1/2 | 7/8 | 2 1/8 | 3/4 | 1 3/16 | 5/16 | 2 7/8 | 1/4 |

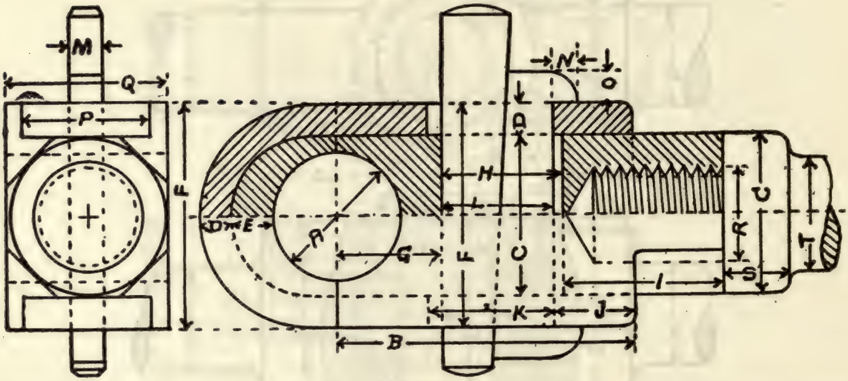
### Valve Rod Knuckle




| A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1/2 | 1 1/8 | 5/8 | 2 1/2 | 3/8 | 1/4 | 7/8 | 13/16 | 1/8 | 1/2 | 1 1/8 | 1/16 |
| 5/8 | 1 1/4 | 3/4 | 2 3/4 | 1/2 | 5/16 | 1 1/8 | 15/16 | 3/16 | 9/16 | 1 7/16 | 1/16 |
| 3/4 | 1 7/16 | 15/16 | 3 | 9/16 | 3/8 | 1 5/16 | 1 | 3/16 | 5/8 | 1 5/8 | 1/16 |
| 7/8 | 1 5/8 | 1 1/8 | 3 1/4 | 11/16 | 3/8 | 1 7/16 | 1 1/8 | 1/4 | 11/16 | 1 13/16 | 1/16 |
| 1 | 1 3/4 | 1 1/4 | 3 1/2 | 3/4 | 7/16 | 1 5/8 | 1 3/16 | 1/4 | 3/4 | 2 | 1/8 |
| 1 1/8 | 2 | 1 3/8 | 4 | 7/8 | 1/2 | 1 7/8 | 1 3/8 | 1/4 | 5/8 | 2 5/16 | 1/8 |
| 1 1/4 | 2 3/16 | 1 1/2 | 4 3/8 | 1 | 9/16 | 2 1/8 | 1 9/16 | 5/16 | 1 | 2 5/8 | 1/8 |
| 1 3/8 | 2 3/8 | 1 3/4 | 4 3/4 | 1 1/8 | 5/8 | 2 3/8 | 1 3/4 | 5/16 | 1 1/8 | 2 15/16 | 1/8 |
| 1 1/2 | 2 5/8 | 1 7/8 | 5 1/4 | 1 1/4 | 11/16 | 2 5/8 | 1 15/16 | 3/8 | 1 1/4 | 3 1/4 | 3/16 |
| 1 5/8 | 2 7/8 | 2 | 5 3/4 | 1 3/8 | 13/16 | 3 | 2 1/8 | 3/8 | 1 3/8 | 3 11/16 | 3/16 |
| 1 3/4 | 3 | 2 3/16 | 6 1/8 | 1 1/2 | 7/8 | 3 1/4 | 2 5/16 | 7/16 | 1 1/2 | 4 | 3/16 |
| 1 7/8 | 3 1/4 | 2 3/8 | 6 5/8 | 1 5/8 | 15/16 | 3 1/2 | 2 1/2 | 7/16 | 1 5/8 | 4 5/16 | 3/16 |
| 2 | 3 1/2 | 2 1/2 | 7 | 1 3/4 | 1 | 3 3/4 | 2 11/16 | 1/2 | 1 3/4 | 4 5/8 | 1/4 |

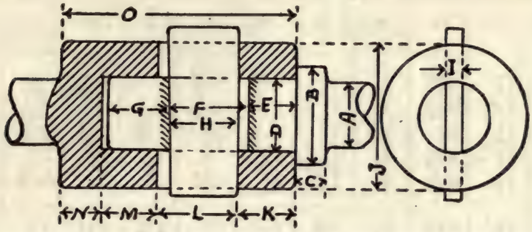
## Strap Joint with Gun Metal Body and Steel Strap

For operating balanced parts. Not suitable for heavy work



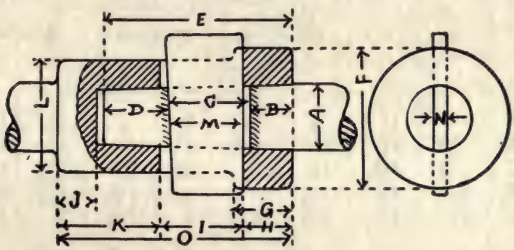

| A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3/4 | 2 3/16 | 1 | 1/4 | 5/16 | 1 1/2 | 13/16 | 13/16 | 1 | 5/8 | 13/16 | 3/4 | 1/4 | 3/16 | 3/16 | 3/4 | 1 | 5/8 | 3/8 | 3/4 |
| 7/8 | 2 1/4 | 1 1/8 | 1/4 | 5/16 | 1 5/8 | 13/16 | 7/8 | 1 1/8 | 5/8 | 7/8 | 13/16 | 1/4 | 3/16 | 3/16 | 7/8 | 1 1/8 | 5/8 | 3/8 | 3/4 |
| 1 | 2 5/16 | 1 1/4 | 1/4 | 5/16 | 1 3/4 | 13/16 | 15/16 | 1 1/4 | 5/8 | 15/16 | 7/8 | 1/4 | 1/4 | 1/4 | 1 | 1 1/4 | 3/4 | 1/2 | 7/8 |
| 1 1/8 | 2 1/2 | 1 3/8 | 1/4 | 3/8 | 1 7/8 | 15/16 | 1 | 1 3/8 | 11/16 | 1 | 7/8 | 1/4 | 1/4 | 1/4 | 1 1/16 | 1 3/8 | 3/4 | 1/2 | 7/8 |
| 1 1/4 | 2 3/4 | 1 1/2 | 5/16 | 3/8 | 2 1/8 | 1 | 1 1/8 | 1 7/16 | 3/4 | 1 1/8 | 1 | 5/16 | 1/4 | 1/4 | 1 1/8 | 1 1/2 | 7/8 | 9/16 | 1 |
| 1 3/8 | 3 | 1 11/16 | 5/16 | 3/8 | 2 5/16 | 1 1/8 | 1 3/16 | 1 1/2 | 13/16 | 1 3/16 | 1 1/16 | 5/16 | 5/16 | 5/16 | 1 1/4 | 1 5/8 | 7/8 | 9/16 | 1 |
| 1 1/2 | 3 3/16 | 1 13/16 | 3/8 | 3/8 | 2 9/16 | 1 3/16 | 1 1/4 | 1 5/8 | 7/8 | 1 1/4 | 1 1/8 | 3/8 | 5/16 | 5/16 | 1 5/16 | 1 3/4 | 1 | 5/8 | 1 1/8 |
| 1 5/8 | 3 3/8 | 2 | 3/8 | 7/16 | 2 3/4 | 1 5/16 | 1 5/16 | 1 11/16 | 7/8 | 1 5/16 | 1 3/16 | 3/8 | 5/16 | 5/16 | 1 3/8 | 1 7/8 | 1 | 5/8 | 1 1/8 |
| 1 3/4 | 3 11/16 | 2 1/8 | 7/16 | 7/16 | 3 | 1 7/16 | 1 7/16 | 1 13/16 | 15/16 | 1 7/16 | 1 5/16 | 7/16 | 3/8 | 3/8 | 1 7/16 | 2 | 1 1/8 | 11/16 | 1 1/4 |
| 1 7/8 | 3 13/16 | 2 1/4 | 7/16 | 7/16 | 3 1/8 | 1 1/2 | 1 1/2 | 1 7/8 | 15/16 | 1 1/2 | 1 3/8 | 7/16 | 3/8 | 3/8 | 1 1/2 | 2 1/8 | 1 1/4 | 11/16 | 1 3/8 |
| 2 | 4 1/8 | 2 3/8 | 1/2 | 1/2 | 3 3/8 | 1 5/8 | 1 5/8 | 2 | 1 | 1 5/8 | 1 1/2 | 1/2 | 3/8 | 3/8 | 1 5/8 | 2 1/4 | 1 1/4 | 3/4 | 1 1/2 |

## Rod Coupling with Collar and Cotter




| Rod Diam. A | Rod Area | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .785 | $1\frac{1}{2}$ | $\frac{1}{2}$ | $1\frac{1}{8}$ | $\frac{3}{4}$ | $1\frac{1}{4}$ | $\frac{7}{8}$ | $1\frac{1}{8}$ | $\frac{1}{4}$ | $2\frac{1}{4}$ | $\frac{7}{8}$ | $1\frac{1}{4}$ | $\frac{7}{8}$ | $\frac{5}{8}$ | $3\frac{5}{8}$ |
| $1\frac{1}{8}$ | .994 | $1\frac{11}{16}$ | $\frac{9}{16}$ | $1\frac{1}{4}$ | $\frac{7}{8}$ | $1\frac{7}{16}$ | 1 | $1\frac{1}{4}$ | $\frac{5}{16}$ | $2\frac{9}{16}$ | 1 | $1\frac{7}{16}$ | 1 | $\frac{11}{16}$ | $4\frac{1}{8}$ |
| $1\frac{1}{4}$ | 1.227 | $1\frac{7}{8}$ | $\frac{5}{8}$ | $1\frac{7}{16}$ | $\frac{15}{16}$ | $1\frac{9}{16}$ | $1\frac{1}{8}$ | $1\frac{7}{16}$ | $\frac{5}{16}$ | $2\frac{7}{8}$ | $1\frac{1}{8}$ | $1\frac{9}{16}$ | $1\frac{1}{8}$ | $\frac{3}{4}$ | $4\frac{9}{16}$ |
| $1\frac{3}{8}$ | 1.485 | $2\frac{1}{16}$ | $\frac{11}{16}$ | $1\frac{9}{16}$ | $1\frac{1}{16}$ | $1\frac{3}{4}$ | $1\frac{3}{16}$ | $1\frac{9}{16}$ | $\frac{3}{8}$ | $3\frac{1}{8}$ | $1\frac{1}{4}$ | $1\frac{3}{4}$ | $1\frac{1}{4}$ | $\frac{13}{16}$ | $5\frac{1}{16}$ |
| $1\frac{1}{2}$ | 1.767 | $2\frac{1}{4}$ | $\frac{3}{4}$ | $1\frac{11}{16}$ | $1\frac{1}{8}$ | $1\frac{7}{8}$ | $1\frac{5}{16}$ | $1\frac{11}{16}$ | $\frac{3}{8}$ | $3\frac{3}{8}$ | $1\frac{8}{8}$ | $1\frac{7}{8}$ | $1\frac{3}{8}$ | $\frac{7}{8}$ | $5\frac{1}{2}$ |
| $1\frac{5}{8}$ | 2.074 | $2\frac{7}{16}$ | $\frac{13}{16}$ | $1\frac{13}{16}$ | $1\frac{1}{4}$ | $2\frac{1}{16}$ | $1\frac{3}{8}$ | $1\frac{7}{8}$ | $\frac{7}{16}$ | $3\frac{5}{8}$ | $1\frac{1}{2}$ | $2\frac{1}{16}$ | $1\frac{1}{2}$ | 1 | $6\frac{1}{16}$ |
| $1\frac{3}{4}$ | 2.405 | $2\frac{5}{8}$ | $\frac{7}{8}$ | $1\frac{15}{16}$ | $1\frac{5}{16}$ | $2\frac{3}{16}$ | $1\frac{1}{2}$ | 2 | $\frac{7}{16}$ | 4 | $1\frac{5}{8}$ | $2\frac{3}{16}$ | $1\frac{9}{16}$ | $1\frac{1}{16}$ | $6\frac{7}{16}$ |
| $1\frac{7}{8}$ | 2.761 | $2\frac{13}{16}$ | $\frac{15}{16}$ | $2\frac{1}{16}$ | $1\frac{7}{16}$ | $2\frac{3}{8}$ | $1\frac{5}{8}$ | $2\frac{1}{8}$ | $\frac{1}{2}$ | $4\frac{1}{4}$ | $1\frac{3}{4}$ | $2\frac{3}{8}$ | $1\frac{11}{16}$ | $1\frac{1}{8}$ | $6\frac{15}{16}$ |
| 2 | 3.142 | 3 | 1 | $2\frac{1}{4}$ | $1\frac{1}{2}$ | $2\frac{1}{2}$ | $1\frac{11}{16}$ | $2\frac{1}{4}$ | $\frac{1}{2}$ | $4\frac{1}{2}$ | $1\frac{13}{16}$ | $2\frac{1}{2}$ | $1\frac{13}{16}$ | $1\frac{3}{16}$ | $7\frac{5}{16}$ |
| $2\frac{1}{4}$ | 3.976 | $3\frac{3}{8}$ | $1\frac{1}{8}$ | $2\frac{1}{2}$ | $1\frac{11}{16}$ | $2\frac{13}{16}$ | $1\frac{7}{8}$ | $2\frac{9}{16}$ | $\frac{9}{16}$ | $5\frac{1}{8}$ | $2\frac{1}{16}$ | $2\frac{13}{16}$ | $2\frac{1}{16}$ | $1\frac{5}{16}$ | $8\frac{1}{4}$ |
| $2\frac{1}{2}$ | 4.909 | $3\frac{3}{4}$ | $1\frac{1}{4}$ | $2\frac{3}{4}$ | $1\frac{7}{8}$ | $3\frac{1}{8}$ | $2\frac{1}{8}$ | $2\frac{13}{16}$ | $\frac{5}{8}$ | $5\frac{5}{8}$ | $2\frac{5}{16}$ | $3\frac{1}{8}$ | $2\frac{5}{16}$ | $1\frac{7}{16}$ | $9\frac{3}{16}$ |
| $2\frac{3}{4}$ | 5.940 | $4\frac{1}{8}$ | $1\frac{3}{8}$ | $3\frac{1}{16}$ | $2\frac{1}{16}$ | $3\frac{7}{16}$ | $2\frac{5}{16}$ | $3\frac{1}{8}$ | $\frac{11}{16}$ | $6\frac{1}{4}$ | $2\frac{9}{16}$ | $3\frac{7}{16}$ | $2\frac{1}{2}$ | $1\frac{5}{8}$ | $10\frac{1}{8}$ |
| 3 | 7.069 | $4\frac{1}{2}$ | $1\frac{1}{2}$ | $3\frac{5}{16}$ | $2\frac{1}{4}$ | $3\frac{3}{4}$ | $2\frac{1}{2}$ | $3\frac{3}{8}$ | $\frac{3}{4}$ | $6\frac{3}{4}$ | $2\frac{3}{4}$ | $3\frac{3}{4}$ | $2\frac{3}{4}$ | $1\frac{3}{4}$ | 11 |

## Rod Coupling with Single Taper Socket and Cotter

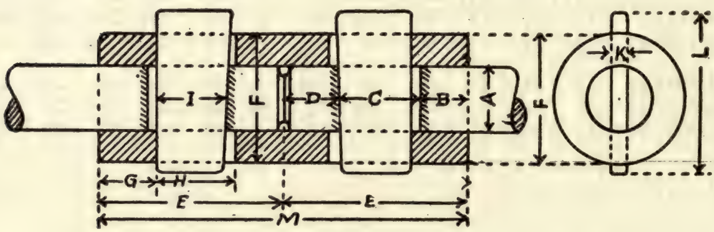



| Diam. A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | $\frac{11}{16}$ | $1\frac{1}{4}$ | 1 | $2\frac{15}{16}$ | $2\frac{1}{8}$ | $\frac{7}{8}$ | $\frac{3}{4}$ | $1\frac{1}{4}$ | $\frac{5}{8}$ | $1\frac{9}{16}$ | $1\frac{3}{4}$ | $1\frac{1}{8}$ | $\frac{1}{4}$ | $3\frac{9}{16}$ |
| $1\frac{1}{8}$ | $\frac{3}{4}$ | $1\frac{7}{16}$ | $1\frac{1}{16}$ | $3\frac{1}{4}$ | $2\frac{3}{8}$ | 1 | $\frac{7}{8}$ | $1\frac{7}{16}$ | $\frac{11}{16}$ | $1\frac{3}{4}$ | 2 | $1\frac{1}{4}$ | $\frac{9}{32}$ | $4\frac{1}{16}$ |
| $1\frac{1}{4}$ | $\frac{7}{8}$ | $1\frac{9}{16}$ | $1\frac{3}{16}$ | $3\frac{5}{8}$ | $2\frac{5}{8}$ | $1\frac{1}{8}$ | 1 | $1\frac{9}{16}$ | $\frac{3}{4}$ | $1\frac{7}{8}$ | $2\frac{3}{16}$ | $1\frac{3}{8}$ | $\frac{5}{16}$ | $4\frac{7}{16}$ |
| $1\frac{3}{8}$ | $\frac{15}{16}$ | $1\frac{3}{4}$ | $1\frac{1}{4}$ | $3\frac{15}{16}$ | $2\frac{7}{8}$ | $1\frac{1}{4}$ | $1\frac{1}{16}$ | $1\frac{3}{4}$ | $\frac{7}{8}$ | $2\frac{1}{8}$ | $2\frac{7}{16}$ | $1\frac{9}{16}$ | $\frac{5}{16}$ | $4\frac{15}{16}$ |
| $1\frac{1}{2}$ | $1\frac{1}{16}$ | $1\frac{7}{8}$ | $1\frac{3}{8}$ | $4\frac{5}{16}$ | $3\frac{1}{8}$ | $1\frac{3}{8}$ | $1\frac{3}{16}$ | $1\frac{7}{8}$ | $\frac{15}{16}$ | $2\frac{3}{8}$ | $2\frac{5}{8}$ | $1\frac{11}{16}$ | $\frac{3}{8}$ | $5\frac{7}{16}$ |

### Rod Coupling with Single Taper Socket and Cotter—(*Continued*)

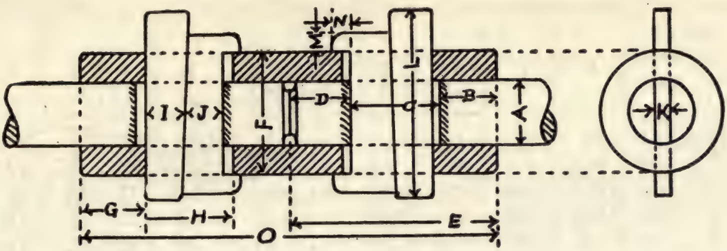
| Diam. A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 5/8 | 1 1/8 | 2 1/16 | 1 1/2 | 4 11/16 | 3 1/2 | 1 1/2 | 1 1/4 | 2 1/16 | 1 | 2 9/16 | 2 7/8 | 1 13/16 | 3/8 | 5 7/8 |
| 1 3/4 | 1 3/16 | 2 3/16 | 1 9/16 | 4 15/16 | 3 3/4 | 1 5/8 | 1 3/8 | 2 3/16 | 1 1/16 | 2 3/4 | 2 1/16 | 2 | 7/16 | 6 5/16 |
| 1 7/8 | 1 1/4 | 2 3/8 | 1 5/8 | 5 1/4 | 4 | 1 3/4 | 1 7/16 | 2 3/8 | 1 3/16 | 2 15/16 | 3 5/16 | 2 1/8 | 7/16 | 6 3/4 |
| 2 | 1 5/16 | 2 1/2 | 1 3/4 | 5 9/16 | 4 1/4 | 1 13/16 | 1 9/16 | 2 1/2 | 1 1/4 | 3 1/8 | 3 1/2 | 2 1/4 | 1/2 | 7 3/16 |
| 2 1/4 | 1 1/2 | 2 13/16 | 1 7/8 | 6 3/16 | 4 7/8 | 2 1/16 | 1 3/4 | 2 13/16 | 1 3/8 | 3 1/2 | 3 15/16 | 2 1/2 | 9/16 | 8 1/16 |
| 2 1/2 | 1 11/16 | 3 1/8 | 2 1/8 | 6 15/16 | 5 3/8 | 2 5/16 | 1 15/16 | 3 1/8 | 1 9/16 | 3 15/16 | 4 3/8 | 2 13/16 | 5/8 | 9 |
| 2 3/4 | 1 13/16 | 3 7/16 | 2 1/4 | 7 1/2 | 5 7/8 | 2 9/16 | 2 1/8 | 3 7/16 | 1 3/4 | 4 3/8 | 2 13/16 | 3 1/8 | 11/16 | 9 15/16 |
| 3 | 2 | 3 3/4 | 2 1/2 | 8 1/4 | 6 1/2 | 2 3/4 | 2 3/8 | 3 3/4 | 1 7/8 | 4 3/4 | 5 1/4 | 3 3/8 | 3/4 | 10 7/8 |

### Rod Coupling with Two Abutting Ends and Cotters



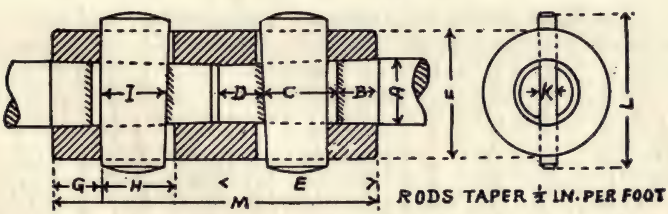

| Rod Diam. A | Rod Area | B | C | D | E | F | G | H | I | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .785 | 3/4 | 1 1/4 | 7/8 | 2 7/8 | 2 | 7/8 | 1 3/8 | 1 1/8 | 1/4 | 2 1/2 | 5 3/4 |
| 1 1/8 | .994 | 13/16 | 1 3/8 | 1 | 3 3/16 | 2 1/4 | 1 | 1 1/2 | 1 1/4 | 9/32 | 2 3/4 | 6 3/8 |
| 1 1/4 | 1.227 | 15/16 | 1 9/16 | 1 1/8 | 3 5/8 | 2 1/2 | 1 1/8 | 1 11/16 | 1 3/8 | 5/16 | 3 1/8 | 7 1/4 |
| 1 3/8 | 1.485 | 1 1/16 | 1 3/4 | 1 3/16 | 4 | 2 3/4 | 1 3/16 | 1 13/16 | 1 9/16 | 5/16 | 3 7/16 | 8 |
| 1 1/2 | 1.767 | 1 1/8 | 1 7/8 | 1 5/16 | 4 5/16 | 3 | 1 5/16 | 2 | 1 11/16 | 3/8 | 3 3/4 | 8 5/8 |
| 1 5/8 | 2.074 | 1 1/4 | 2 1/16 | 1 7/16 | 4 3/4 | 3 1/4 | 1 7/16 | 2 1/8 | 1 13/16 | 3/8 | 4 1/16 | 9 1/2 |
| 1 3/4 | 2.405 | 1 5/16 | 2 3/16 | 1 9/16 | 5 1/16 | 3 1/2 | 1 9/16 | 2 1/4 | 2 | 7/16 | 4 3/8 | 10 1/8 |
| 1 7/8 | 2.761 | 1 7/16 | 2 3/8 | 1 5/8 | 5 7/16 | 3 3/4 | 1 5/8 | 2 7/16 | 2 1/8 | 7/16 | 4 11/16 | 10 7/8 |
| 2 | 3.142 | 1 1/2 | 2 1/2 | 1 3/4 | 5 3/4 | 4 | 1 3/4 | 2 9/16 | 2 1/4 | 1/2 | 5 | 11 1/2 |
| 2 1/4 | 3.976 | 1 11/16 | 2 13/16 | 2 | 6 1/2 | 4 1/2 | 2 | 2 7/8 | 2 1/2 | 9/16 | 5 5/8 | 13 |
| 2 1/2 | 4.909 | 1 7/8 | 3 1/8 | 2 3/16 | 7 3/16 | 5 | 2 3/16 | 3 3/16 | 2 13/16 | 5/8 | 6 1/4 | 14 3/8 |
| 2 3/4 | 5.940 | 2 1/16 | 3 7/16 | 2 3/8 | 7 7/8 | 5 1/2 | 2 3/8 | 3 7/16 | 3 1/8 | 11/16 | 6 7/8 | 15 3/4 |
| 3 | 7.069 | 2 1/4 | 3 3/4 | 2 5/8 | 8 5/8 | 6 | 2 5/8 | 3 3/4 | 3 3/8 | 3/4 | 7 1/2 | 17 1/4 |

## Rod Coupling with Two Abutting Ends. Gib and Key




| Dia. A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 7/8 | 1 3/8 | 1 | 3 1/4 | 1 7/8 | 1 | 1 3/8 | 5/8 | 5/8 | 1/4 | 2 7/8 | 5/16 | 1/4 | 6 1/2 |
| 1 1/8 | 1 | 1 9/16 | 1 1/8 | 3 11/16 | 2 1/8 | 1 1/8 | 1 1/2 | 11/16 | 11/16 | 9/32 | 3 3/16 | 3/8 | 9/32 | 7 3/8 |
| 1 1/4 | 1 1/8 | 1 3/4 | 1 1/4 | 4 1/8 | 2 3/8 | 1 1/4 | 1 11/16 | 3/4 | 3/4 | 5/16 | 3 5/8 | 3/8 | 5/16 | 8 1/4 |
| 1 3/8 | 1 3/16 | 1 7/8 | 1 3/8 | 4 7/16 | 2 5/8 | 1 3/8 | 1 7/8 | 7/8 | 7/8 | 5/16 | 4 | 7/16 | 5/16 | 8 7/8 |
| 1 1/2 | 1 5/16 | 2 1/16 | 1 1/2 | 4 7/8 | 2 7/8 | 1 1/2 | 2 1/16 | 15/16 | 15/16 | 3/8 | 4 5/16 | 1/2 | 3/8 | 9 3/4 |
| 1 5/8 | 1 7/16 | 2 1/4 | 1 5/8 | 5 5/16 | 3 1/8 | 1 5/8 | 2 1/4 | 1 | 1 | 3/8 | 4 3/4 | 1/2 | 3/8 | 10 5/8 |
| 1 3/4 | 1 9/16 | 2 7/16 | 1 3/4 | 5 3/4 | 3 3/8 | 1 3/4 | 2 3/8 | 1 1/16 | 1 1/16 | 7/16 | 5 1/16 | 9/16 | 7/16 | 11 1/2 |
| 1 7/8 | 1 5/8 | 2 9/16 | 1 7/8 | 6 1/16 | 3 9/16 | 1 7/8 | 2 9/16 | 1 3/16 | 1 3/16 | 7/16 | 5 7/16 | 9/16 | 7/16 | 12 1/8 |
| 2 | 1 3/4 | 2 3/4 | 2 | 6 1/2 | 3 13/16 | 2 | 2 3/4 | 1 1/4 | 1 1/4 | 1/2 | 5 3/4 | 5/8 | 1/2 | 13 |
| 2 1/4 | 2 | 3 1/16 | 2 1/4 | 7 5/16 | 4 5/16 | 2 1/4 | 3 1/8 | 1 3/8 | 1 3/8 | 9/16 | 6 1/2 | 11/16 | 9/16 | 14 5/8 |
| 2 1/2 | 2 3/16 | 3 7/16 | 2 1/2 | 8 1/8 | 4 3/4 | 2 1/2 | 3 7/16 | 1 9/16 | 1 9/16 | 5/8 | 7 3/16 | 3/4 | 5/8 | 16 1/4 |
| 2 3/4 | 2 3/8 | 3 3/4 | 2 3/4 | 8 7/8 | 5 1/4 | 2 3/4 | 3 13/16 | 1 3/4 | 1 3/4 | 11/16 | 7 7/8 | 13/16 | 11/16 | 17 3/4 |
| 3 | 2 5/8 | 4 1/8 | 3 | 9 3/4 | 5 3/4 | 3 | 4 1/8 | 1 7/8 | 1 7/8 | 3/4 | 8 5/8 | 7/8 | 3/4 | 19 1/2 |

## Rod Coupling with Two Taper Ends and Cotters

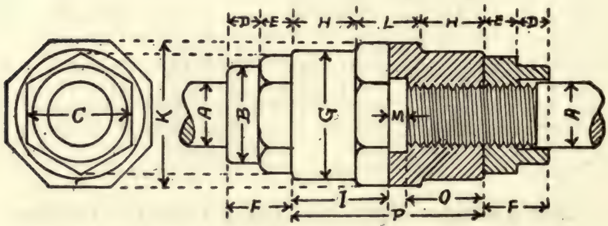



| Rod | | B | C | D | E | F | G | H | I | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Diam. A | Area | | | | | | | | | | | |
| 1 | .785 | 5/8 | 1 1/8 | 3/4 | 2 3/8 | 2 | 3/4 | 1 1/8 | 1 | 1/4 | 2 3/8 | 5 |
| 1 1/8 | .994 | 11/16 | 1 5/16 | 13/16 | 2 3/4 | 2 1/4 | 7/8 | 1 5/16 | 1 1/8 | 9/32 | 2 3/4 | 5 5/8 |
| 1 1/4 | 1.227 | 3/4 | 1 7/16 | 15/16 | 3 | 2 1/2 | 15/16 | 1 1/2 | 1 1/4 | 5/16 | 3 | 6 1/2 |
| 1 3/8 | 1.485 | 13/16 | 1 9/16 | 1 | 3 3/8 | 2 3/4 | 1 1/16 | 1 11/16 | 1 3/8 | 5/16 | 3 3/8 | 7 |
| 1 1/2 | 1.767 | 15/16 | 1 3/4 | 1 1/16 | 3 11/16 | 3 | 1 1/8 | 1 7/8 | 1 1/2 | 3/8 | 3 11/16 | 7 1/2 |

Rod Coupling with Two Taper Ends and Cotters—(*Continued*)

| Rod | | B | C | D | E | F | G | H | I | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Diam. A | Area | | | | | | | | | | | |
| $1\frac{5}{8}$ | 2.074 | 1 | $1\frac{7}{8}$ | $1\frac{3}{16}$ | 4 | $3\frac{1}{4}$ | $1\frac{1}{4}$ | $2\frac{1}{16}$ | $1\frac{5}{8}$ | $\frac{3}{8}$ | 4 | $8\frac{1}{8}$ |
| $1\frac{3}{4}$ | 2.405 | $1\frac{1}{16}$ | 2 | $1\frac{1}{4}$ | $4\frac{5}{16}$ | $3\frac{1}{2}$ | $1\frac{5}{16}$ | $2\frac{1}{4}$ | $1\frac{3}{4}$ | $\frac{7}{16}$ | $4\frac{5}{16}$ | $8\frac{3}{4}$ |
| $1\frac{7}{8}$ | 2.761 | $1\frac{1}{8}$ | $2\frac{3}{16}$ | $1\frac{5}{16}$ | $4\frac{5}{8}$ | $3\frac{3}{4}$ | $1\frac{7}{16}$ | $2\frac{5}{16}$ | $1\frac{7}{8}$ | $\frac{7}{16}$ | $4\frac{5}{8}$ | $9\frac{3}{8}$ |
| 2 | 3.142 | $1\frac{3}{16}$ | $2\frac{5}{16}$ | $1\frac{3}{8}$ | $4\frac{15}{16}$ | 4 | $1\frac{1}{2}$ | $2\frac{9}{16}$ | 2 | $\frac{1}{2}$ | $4\frac{15}{16}$ | 10 |
| $2\frac{1}{4}$ | 3.976 | $1\frac{5}{16}$ | $2\frac{5}{8}$ | $1\frac{9}{16}$ | $5\frac{9}{16}$ | $4\frac{1}{2}$ | $1\frac{11}{16}$ | $2\frac{15}{16}$ | $2\frac{1}{4}$ | $\frac{9}{16}$ | $5\frac{9}{16}$ | $11\frac{1}{4}$ |
| $2\frac{1}{2}$ | 4.909 | $1\frac{1}{2}$ | $2\frac{7}{8}$ | $1\frac{11}{16}$ | $6\frac{3}{16}$ | 5 | $1\frac{7}{8}$ | $3\frac{5}{16}$ | $2\frac{1}{2}$ | $\frac{5}{8}$ | $6\frac{3}{16}$ | $12\frac{1}{2}$ |
| $2\frac{3}{4}$ | 5.940 | $1\frac{5}{8}$ | $3\frac{3}{16}$ | $1\frac{7}{8}$ | $6\frac{7}{8}$ | $5\frac{1}{2}$ | $2\frac{1}{16}$ | $3\frac{5}{8}$ | $2\frac{3}{4}$ | $\frac{11}{16}$ | $6\frac{7}{8}$ | $13\frac{3}{4}$ |
| 3 | 7.069 | $1\frac{3}{4}$ | $3\frac{1}{2}$ | 2 | $7\frac{1}{2}$ | 6 | $2\frac{1}{4}$ | 4 | 3 | $\frac{3}{4}$ | $7\frac{1}{2}$ | 15 |

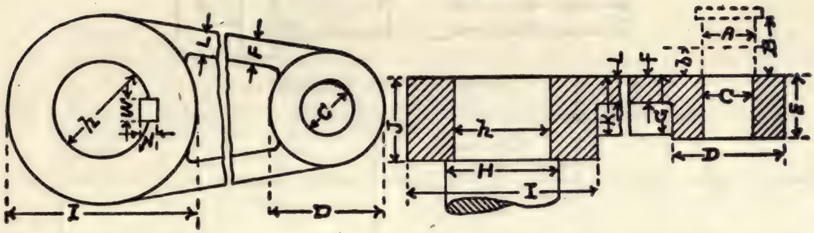
Screw Coupling. Adjustable with Lock Nuts




Right and left hand threads. United States Standard

| A | B | C | D | E | F | G | H | I | K | L | M | N | O | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\frac{1}{2}$ | $\frac{3}{4}$ | $\frac{7}{8}$ | $\frac{1}{4}$ | $\frac{1}{4}$ | $\frac{1}{2}$ | $1\frac{1}{8}$ | $\frac{1}{2}$ | $\frac{3}{4}$ | $1\frac{1}{4}$ | $\frac{1}{2}$ | $\frac{1}{8}$ | $\frac{5}{8}$ | $\frac{5}{8}$ | $1\frac{1}{2}$ |
| $\frac{5}{8}$ | $\frac{15}{16}$ | $1\frac{1}{16}$ | $\frac{5}{16}$ | $\frac{5}{16}$ | $\frac{5}{8}$ | $1\frac{11}{32}$ | $\frac{21}{32}$ | $\frac{15}{16}$ | $1\frac{7}{16}$ | $\frac{9}{16}$ | $\frac{1}{8}$ | $\frac{3}{4}$ | $\frac{13}{16}$ | $1\frac{7}{8}$ |
| $\frac{3}{4}$ | $1\frac{1}{8}$ | $1\frac{1}{4}$ | $\frac{13}{32}$ | $\frac{11}{32}$ | $\frac{3}{4}$ | $1\frac{9}{16}$ | $\frac{13}{16}$ | $1\frac{1}{8}$ | $1\frac{11}{16}$ | $\frac{5}{8}$ | $\frac{1}{8}$ | $\frac{7}{8}$ | 1 | $2\frac{1}{4}$ |
| $\frac{7}{8}$ | $1\frac{5}{16}$ | $1\frac{7}{16}$ | $\frac{1}{2}$ | $\frac{3}{8}$ | $\frac{7}{8}$ | $1\frac{25}{32}$ | $\frac{15}{16}$ | $1\frac{5}{16}$ | $1\frac{7}{8}$ | $\frac{3}{4}$ | $\frac{3}{16}$ | 1 | $1\frac{1}{8}$ | $2\frac{5}{8}$ |
| 1 | $1\frac{1}{2}$ | $1\frac{5}{8}$ | $\frac{19}{32}$ | $\frac{13}{32}$ | 1 | 2 | $1\frac{3}{32}$ | $1\frac{1}{2}$ | $2\frac{1}{8}$ | $\frac{13}{16}$ | $\frac{3}{16}$ | $1\frac{1}{8}$ | $1\frac{5}{16}$ | 3 |
| $1\frac{1}{8}$ | $1\frac{11}{16}$ | $1\frac{13}{16}$ | $\frac{21}{32}$ | $\frac{15}{32}$ | $1\frac{1}{8}$ | $2\frac{7}{32}$ | $1\frac{7}{32}$ | $1\frac{11}{16}$ | $2\frac{5}{16}$ | $\frac{15}{16}$ | $\frac{3}{16}$ | $1\frac{1}{4}$ | $1\frac{1}{2}$ | $3\frac{3}{8}$ |
| $1\frac{1}{4}$ | $1\frac{7}{8}$ | 2 | $\frac{3}{4}$ | $\frac{1}{2}$ | $1\frac{1}{4}$ | $2\frac{7}{16}$ | $1\frac{3}{8}$ | $1\frac{7}{8}$ | $2\frac{9}{16}$ | 1 | $\frac{1}{4}$ | $1\frac{3}{8}$ | $1\frac{5}{8}$ | $3\frac{3}{4}$ |
| $1\frac{3}{8}$ | $2\frac{1}{16}$ | $2\frac{3}{16}$ | $\frac{13}{16}$ | $\frac{9}{16}$ | $1\frac{3}{8}$ | $2\frac{21}{32}$ | $1\frac{17}{32}$ | $2\frac{1}{16}$ | $2\frac{3}{4}$ | $1\frac{1}{16}$ | $\frac{1}{4}$ | $1\frac{1}{2}$ | $1\frac{13}{16}$ | $4\frac{1}{8}$ |
| $1\frac{1}{2}$ | $2\frac{1}{4}$ | $2\frac{3}{8}$ | $\frac{29}{32}$ | $\frac{19}{32}$ | $1\frac{1}{2}$ | $2\frac{7}{8}$ | $1\frac{11}{16}$ | $2\frac{1}{4}$ | 3 | $1\frac{1}{8}$ | $\frac{1}{4}$ | $1\frac{5}{8}$ | 2 | $4\frac{1}{2}$ |
| $1\frac{5}{8}$ | $2\frac{7}{16}$ | $2\frac{9}{16}$ | 1 | $\frac{5}{8}$ | $1\frac{5}{8}$ | $3\frac{1}{8}$ | $1\frac{13}{16}$ | $2\frac{7}{16}$ | $3\frac{1}{4}$ | $1\frac{1}{4}$ | $\frac{5}{16}$ | $1\frac{3}{4}$ | $2\frac{1}{8}$ | $4\frac{7}{8}$ |
| $1\frac{3}{4}$ | $2\frac{5}{8}$ | $2\frac{3}{4}$ | $1\frac{1}{16}$ | $\frac{11}{16}$ | $1\frac{3}{4}$ | $3\frac{5}{16}$ | $1\frac{31}{32}$ | $2\frac{5}{8}$ | $3\frac{7}{16}$ | $1\frac{5}{16}$ | $\frac{5}{16}$ | $1\frac{7}{8}$ | $2\frac{5}{16}$ | $5\frac{1}{4}$ |
| $1\frac{7}{8}$ | $2\frac{13}{16}$ | $2\frac{15}{16}$ | $1\frac{5}{32}$ | $\frac{23}{32}$ | $1\frac{7}{8}$ | $3\frac{9}{16}$ | $2\frac{1}{8}$ | $2\frac{13}{16}$ | $3\frac{5}{8}$ | $1\frac{3}{8}$ | $\frac{5}{16}$ | 2 | $2\frac{1}{2}$ | $5\frac{5}{8}$ |
| 2 | 3 | $3\frac{1}{8}$ | $1\frac{1}{4}$ | $\frac{3}{4}$ | 2 | $3\frac{3}{4}$ | $2\frac{1}{4}$ | 3 | $3\frac{7}{8}$ | $1\frac{1}{2}$ | $\frac{3}{8}$ | $2\frac{1}{8}$ | $2\frac{5}{8}$ | 6 |

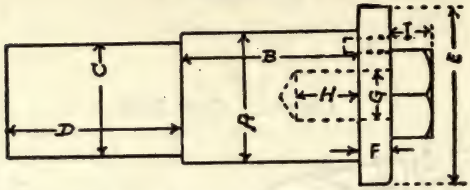
## Cranks. Cast Iron




Suitable for Steam Engines up to 24 In. Diameter of Cylinder; Steam Pressures No More than 125 Pounds. For Higher Pressures Steel Castings Should be Used.

| Crank Pin End | | | | | | | | Shaft End | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | B | b | C | D | E | F | G | H | h | I | J | K | L | M | N |
| 1 | 1 3/8 | 11/16 | 7/8 | 1 3/4 | 1 3/8 | 3/4 | 1 1/8 | 2 | 1 3/4 | 3 3/4 | 2 | 1 3/8 | 7/8 | 9/16 | 9/32 |
| 1 1/4 | 1 5/8 | 13/16 | 1 1/8 | 2 1/4 | 1 5/8 | 13/16 | 1 3/8 | 2 1/2 | 2 1/4 | 4 3/4 | 2 1/4 | 1 5/8 | 15/16 | 11/16 | 11/32 |
| 1 1/2 | 1 7/8 | 15/16 | 1 3/8 | 2 3/4 | 1 7/8 | 7/8 | 1 11/16 | 3 | 2 3/4 | 5 3/4 | 2 9/16 | 2 | 1 | 13/16 | 13/32 |
| 1 3/4 | 2 1/8 | 1 1/16 | 1 5/8 | 3 1/4 | 2 1/8 | 15/16 | 1 15/16 | 3 1/2 | 3 1/4 | 6 1/2 | 2 7/8 | 2 1/4 | 1 1/16 | 15/16 | 15/32 |
| 2 | 2 3/8 | 1 3/16 | 1 7/8 | 3 3/4 | 2 3/8 | 1 | 2 3/16 | 4 | 3 3/4 | 7 3/8 | 3 1/8 | 2 5/8 | 1 1/8 | 1 1/16 | 17/32 |
| 2 1/4 | 2 5/8 | 1 5/16 | 2 1/8 | 4 1/4 | 2 5/8 | 1 1/16 | 2 1/2 | 4 1/2 | 4 1/8 | 8 1/8 | 3 9/16 | 2 7/8 | 1 3/16 | 1 1/8 | 9/16 |
| 2 1/2 | 2 7/8 | 1 7/16 | 2 1/4 | 4 1/2 | 2 7/8 | 1 1/8 | 2 3/4 | 5 | 4 1/2 | 9 | 3 13/16 | 3 1/8 | 1 1/4 | 1 1/4 | 5/8 |
| 2 3/4 | 3 1/8 | 1 9/16 | 2 1/2 | 5 | 3 1/8 | 1 3/16 | 3 | 5 1/2 | 4 7/8 | 9 3/4 | 4 1/16 | 3 1/2 | 1 5/16 | 1 5/16 | 21/32 |
| 3 | 3 1/2 | 1 3/4 | 2 3/4 | 5 1/2 | 3 1/2 | 1 1/4 | 3 1/4 | 6 | 5 1/8 | 10 1/2 | 4 7/16 | 3 3/4 | 1 7/16 | 1 3/8 | 11/16 |
| 3 1/4 | 3 3/4 | 1 7/8 | 3 | 6 | 3 3/4 | 1 5/16 | 3 1/2 | 6 1/2 | 5 1/2 | 11 1/4 | 4 3/4 | 4 1/8 | 1 1/2 | 1 1/2 | 3/4 |
| 3 1/2 | 4 1/8 | 2 1/16 | 3 1/4 | 6 1/2 | 4 1/8 | 1 3/8 | 3 3/4 | 7 | 6 | 12 | 5 | 4 3/8 | 1 9/16 | 1 5/8 | 13/16 |
| 3 3/4 | 4 3/8 | 2 3/16 | 3 1/2 | 7 | 4 3/8 | 1 7/16 | 4 1/8 | 7 1/2 | 6 1/4 | 12 7/8 | 5 1/4 | 4 3/4 | 1 5/8 | 1 11/16 | 27/32 |
| 4 | 4 3/4 | 2 3/8 | 3 3/4 | 7 1/2 | 4 3/4 | 1 1/2 | 4 3/8 | 8 | 6 5/8 | 13 5/8 | 5 3/4 | 5 | 1 11/16 | 1 13/16 | 29/32 |
| 4 1/4 | 5 | 2 1/2 | 4 | 8 | 5 | 1 9/16 | 4 5/8 | 8 1/2 | 7 | 14 1/2 | 5 15/16 | 5 3/8 | 1 3/4 | 1 7/8 | 15/16 |
| 4 1/2 | 5 1/4 | 2 5/8 | 4 1/4 | 8 1/2 | 5 1/4 | 1 5/8 | 4 7/8 | 9 | 7 3/8 | 15 1/4 | 6 3/16 | 5 5/8 | 1 13/16 | 1 15/16 | 31/32 |
| 4 3/4 | 5 1/2 | 2 3/4 | 4 1/2 | 9 | 5 1/2 | 1 11/16 | 5 1/8 | 9 1/2 | 7 3/4 | 16 | 6 11/16 | 6 | 1 7/8 | 2 1/16 | 1 1/32 |
| 5 | 5 7/8 | 2 15/16 | 4 3/4 | 9 1/2 | 5 7/8 | 1 3/4 | 5 1/2 | 10 | 8 1/8 | 16 7/8 | 6 7/8 | 6 1/4 | 1 15/16 | 2 1/8 | 1 1/16 |
| 5 1/4 | 6 1/8 | 3 1/16 | 5 | 10 | 6 1/8 | 1 13/16 | 5 3/4 | 10 1/2 | 8 1/2 | 17 5/8 | 7 1/4 | 6 1/2 | 2 | 2 1/4 | 1 1/8 |
| 5 1/2 | 6 3/8 | 3 3/16 | 5 1/4 | 10 1/2 | 6 3/8 | 1 7/8 | 6 | 11 | 8 7/8 | 18 1/2 | 7 5/8 | 6 7/8 | 2 1/16 | 2 3/8 | 1 3/16 |
| 5 3/4 | 6 3/4 | 3 3/8 | 5 1/2 | 11 | 6 3/4 | 1 15/16 | 6 1/4 | 11 1/2 | 9 1/4 | 19 1/4 | 8 | 7 1/8 | 2 1/8 | 2 7/16 | 1 7/32 |
| 6 | 7 | 3 1/2 | 5 3/4 | 11 1/2 | 7 | 2 | 6 1/2 | 12 | 9 1/2 | 20 | 8 1/4 | 7 1/2 | 2 1/4 | 2 1/2 | 1 1/4 |

## Crank Pins



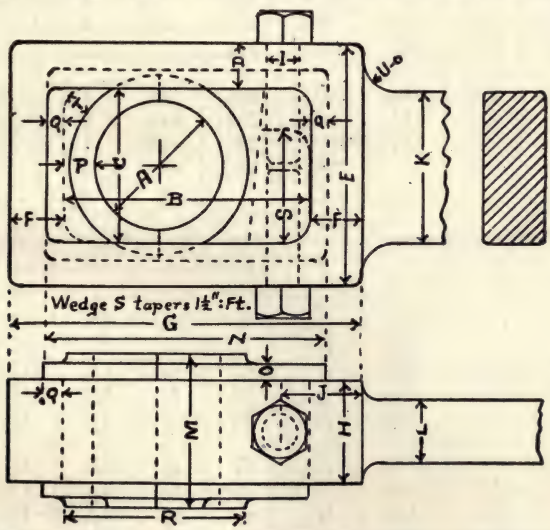

For Stationary Engines

| Diam. A | Area A | Length B | Projected Area Sq. In. | Pressure on Pin at 1500 Lbs. Sq. In. | Diam. C | Area C | Length D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .7854 | 1⅜ | 1.375 | 2 063 | ⅞ | .601 | 1⅜ | 1⅜ | ¼ | ⅜ | ¾ | $\frac{11}{32}$ |
| 1⅛ | .994 | 1½ | 1.688 | 2 532 | 1 | .785 | 1½ | 1½ | ¼ | ⅜ | ¾ | $\frac{11}{32}$ |
| 1¼ | 1.227 | 1⅝ | 2.031 | 3 047 | 1⅛ | .994 | 1⅝ | $1\frac{11}{16}$ | ¼ | ⅜ | ¾ | $\frac{11}{32}$ |
| 1⅜ | 1.485 | 1¾ | 2.406 | 3 609 | 1¼ | 1.227 | 1¾ | $1\frac{13}{16}$ | $\frac{5}{16}$ | $\frac{7}{16}$ | ⅞ | $\frac{25}{64}$ |
| 1½ | 1.767 | 1⅞ | 2.813 | 4 220 | 1⅜ | 1.485 | 1⅞ | 2 | ⅜ | $\frac{7}{16}$ | ⅞ | $\frac{25}{64}$ |
| 1⅝ | 2.074 | 2 | 3.250 | 4 875 | 1½ | 1.767 | 2 | 2⅛ | ⅜ | ½ | 1 | $\frac{7}{16}$ |
| 1¾ | 2.405 | 2⅛ | 3.719 | 5 579 | 1⅝ | 2.074 | 2⅛ | 2¼ | ⅜ | ½ | 1 | $\frac{7}{16}$ |
| 1⅞ | 2.761 | 2¼ | 4.219 | 6 329 | 1¾ | 2.405 | 2¼ | $2\frac{7}{16}$ | ⅜ | ½ | 1 | $\frac{7}{16}$ |
| 2 | 3.142 | 2⅜ | 4.750 | 7 125 | 1⅞ | 2.761 | 2⅜ | $2\frac{9}{16}$ | $\frac{7}{16}$ | $\frac{9}{16}$ | 1⅛ | $\frac{31}{64}$ |
| 2⅛ | 3.547 | 2½ | 5.313 | 7 970 | 2 | 3.142 | 2½ | $2\frac{11}{16}$ | $\frac{7}{16}$ | $\frac{9}{16}$ | 1⅛ | $\frac{31}{64}$ |
| 2¼ | 3.976 | 2⅝ | 5.906 | 8 859 | 2⅛ | 3.547 | 2⅝ | 2⅞ | $\frac{7}{16}$ | $\frac{9}{16}$ | 1⅛ | $\frac{31}{64}$ |
| 2⅜ | 4.430 | 2¾ | 6.531 | 9 797 | 2¼ | 3.976 | 2¾ | 3 | ½ | $\frac{9}{16}$ | 1⅛ | $\frac{31}{64}$ |
| 2½ | 4.909 | 2⅞ | 7.188 | 10 782 | 2¼ | 3.976 | 2⅞ | 3⅛ | ½ | ⅝ | 1¼ | $\frac{17}{32}$ |
| 2⅝ | 5.412 | 3 | 7.875 | 11 813 | 2⅜ | 4.430 | 3 | $3\frac{5}{16}$ | ½ | ⅝ | 1¼ | $\frac{17}{32}$ |
| 2¾ | 5.940 | 3⅛ | 8.594 | 12 891 | 2½ | 4.909 | 3⅛ | $3\frac{7}{16}$ | ½ | ⅝ | 1¼ | $\frac{17}{32}$ |
| 2⅞ | 6.492 | 3¼ | 9.344 | 14 016 | 2⅝ | 5.412 | 3¼ | $3\frac{9}{16}$ | $\frac{9}{16}$ | ⅝ | 1¼ | $\frac{17}{32}$ |
| 3 | 7.069 | 3½ | 10.500 | 15 750 | 2¾ | 5.940 | 3½ | 3¾ | $\frac{9}{16}$ | ¾ | 1½ | ⅝ |
| 3¼ | 8.296 | 3¾ | 12.188 | 18 282 | 3 | 7.069 | 3¾ | 4 | ⅝ | ¾ | 1½ | ⅝ |
| 3½ | 9.621 | 4⅛ | 14.438 | 21 657 | 3¼ | 8.296 | 4⅛ | $4\frac{5}{16}$ | $\frac{11}{16}$ | ¾ | 1½ | ⅝ |
| 3¾ | 11.045 | 4⅜ | 16.406 | 24 609 | 3½ | 9.621 | 4⅜ | 4⅝ | ¾ | ¾ | 1½ | ⅝ |
| 4 | 12.566 | 4¾ | 19.000 | 28 500 | 3¾ | 11.045 | 4¾ | 4⅞ | ¾ | ⅞ | 1¾ | $\frac{23}{32}$ |
| 4¼ | 14.186 | 5 | 21.250 | 31 875 | 4 | 12.566 | 5 | 5⅛ | ¾ | ⅞ | 1¾ | $\frac{23}{32}$ |
| 4½ | 15.904 | 5¼ | 23.625 | 35 438 | 4¼ | 14.186 | 5¼ | 5⅜ | ¾ | ⅞ | 1¾ | $\frac{23}{32}$ |
| 4¾ | 17.721 | 5½ | 26.125 | 39 188 | 4½ | 15.904 | 5½ | 5⅝ | $\frac{13}{16}$ | ⅞ | 1¾ | $\frac{23}{32}$ |
| 5 | 19.635 | 5⅞ | 29.375 | 44 063 | 4¾ | 17.721 | 5⅞ | 6 | $\frac{13}{16}$ | ⅞ | 1¾ | $\frac{23}{32}$ |
| 5¼ | 21.648 | 6⅛ | 32.156 | 48 234 | 5 | 19.635 | 6⅛ | 6¼ | $\frac{13}{16}$ | ⅞ | 1¾ | $\frac{23}{32}$ |
| 5½ | 23.758 | 6⅜ | 35.063 | 52 594 | 5¼ | 21.648 | 6⅜ | 6⅝ | $\frac{13}{16}$ | ⅞ | 1¾ | $\frac{23}{32}$ |
| 5¾ | 25.967 | 6¾ | 38.813 | 58 219 | 5½ | 23.758 | 6¾ | 6⅞ | ⅞ | ⅞ | 1¾ | $\frac{23}{32}$ |
| 6 | 28.274 | 7 | 42.000 | 63 000 | 5¾ | 25.967 | 7 | 7⅛ | ⅞ | 1 | 2 | $\frac{13}{16}$ |
| 6¼ | 30.680 | 7¼ | 45.313 | 67 970 | 6 | 28.274 | 7¼ | 7⅜ | ⅞ | 1 | 2 | $\frac{13}{16}$ |
| 6½ | 33.183 | 7⅝ | 49.563 | 74 345 | 6¼ | 30.680 | 7⅝ | 7⅝ | ⅞ | 1 | 2 | $\frac{13}{16}$ |
| 6¾ | 35.785 | 7⅞ | 53.156 | 79 734 | 6½ | 33.183 | 7⅞ | 8 | ⅞ | 1 | 2 | $\frac{13}{16}$ |
| 7 | 38.485 | 8⅛ | 56.875 | 85 313 | 6¾ | 35.785 | 8⅛ | 8¼ | ⅞ | 1 | 2 | $\frac{13}{16}$ |
| 7¼ | 41.282 | 8½ | 61.625 | 92 438 | 7 | 38.485 | 8½ | 8½ | $\frac{15}{16}$ | 1 | 2 | $\frac{13}{16}$ |
| 7½ | 44.179 | 8¾ | 65.625 | 98 438 | 7¼ | 41.282 | 8¾ | 8⅞ | $\frac{15}{16}$ | 1 | 2 | $\frac{13}{16}$ |

CRANK PINS. For Stationary Engines—(*Continued*)

| Diam. A | Area A | Length B | Projected Area Sq. In. | Pressure on Pin at 1500 Lbs. Sq. In. | Diam. C | Area C | Length D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7¾ | 47.173 | 9 | 69.750 | 104 625 | 7½ | 44.179 | 9 | 9⅛ | 15/16 | 1 | 2 | 13/16 |
| 8 | 50.265 | 9⅜ | 75.000 | 112 500 | 7¾ | 47.173 | 9⅜ | 9⅜ | 1 | 1⅛ | 2¼ | 29/32 |
| 8¼ | 53.456 | 9⅝ | 79.406 | 119 109 | 8 | 50.265 | 9⅝ | 9⅝ | 1 | 1⅛ | 2¼ | 29/32 |
| 8½ | 56.745 | 10 | 85.000 | 127 500 | 8¼ | 53.456 | 10 | 10 | 1 | 1⅛ | 2¼ | 29/32 |
| 8¾ | 60.132 | 10¼ | 89.688 | 134 532 | 8½ | 56.745 | 10¼ | 10⅜ | 1 | 1⅛ | 2¼ | 29/32 |
| 9 | 63.617 | 10½ | 94.500 | 141 750 | 8¾ | 60.132 | 10½ | 10⅝ | 1 | 1⅛ | 2¼ | 29/32 |
| 9¼ | 67.201 | 10¾ | 99.438 | 149 157 | 9 | 63.617 | 10¾ | 10⅞ | 1 | 1⅛ | 2¼ | 29/32 |
| 9½ | 70.882 | 11⅛ | 105.688 | 158 532 | 9¼ | 67.201 | 11⅛ | 11⅛ | 1 | 1⅛ | 2¼ | 29/32 |
| 9¾ | 74.662 | 11⅜ | 110.906 | 166 359 | 9½ | 70.882 | 11⅜ | 11½ | 1 | 1⅛ | 2¼ | 29/32 |
| 10 | 78.540 | 11⅝ | 116.250 | 174 375 | 9¾ | 74.662 | 11⅝ | 11¾ | 1 | 1¼ | 2½ | 1 |
| 10¼ | 82.516 | 12 | 123.000 | 184 500 | 10 | 78.540 | 12 | 12 | 1 | 1¼ | 2½ | 1 |
| 10½ | 86.590 | 12¼ | 128.625 | 192 938 | 10¼ | 82.516 | 12¼ | 12¼ | 1 | 1¼ | 2½ | 1 |
| 10¾ | 90.763 | 12½ | 134.375 | 201 563 | 10½ | 86.590 | 12½ | 12⅝ | 1 | 1¼ | 2½ | 1 |
| 11 | 95.033 | 12⅞ | 141.625 | 212 438 | 10¾ | 90.763 | 12⅞ | 12⅞ | 1⅛ | 1¼ | 2½ | 1 |
| 11¼ | 99.402 | 13⅛ | 147.656 | 221 484 | 11 | 95.033 | 13⅛ | 13⅛ | 1⅛ | 1¼ | 2½ | 1 |
| 11½ | 103.869 | 13½ | 155.250 | 232 875 | 11¼ | 99.402 | 13½ | 13½ | 1⅛ | 1¼ | 2½ | 1 |
| 11¾ | 108.434 | 13¾ | 161.563 | 242 345 | 11½ | 103.869 | 13¾ | 13¾ | 1⅛ | 1¼ | 2½ | 1 |
| 12 | 113.097 | 14 | 168.000 | 252 000 | 11¾ | 108.434 | 14 | 14 | 1⅛ | 1¼ | 2½ | 1 |

CONNECTING ROD STUB END, FOR CRANK PIN. BOX END WITH WEDGE ADJUSTMENT




| A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2⅛ | 1 3/16 | ⅜ | 1 15/16 | 7/16 | 3 | ⅞ | 5/16 | 11/16 | 1 3/16 |
| 1⅛ | 2⅜ | 1⅜ | 7/16 | 2¼ | ½ | 3⅜ | 1 | 5/16 | ¾ | 1⅜ |
| 1¼ | 2 9/16 | 1½ | 7/16 | 2⅜ | 9/16 | 3 11/16 | 1 1/16 | ⅜ | 13/16 | 1½ |
| 1⅜ | 2¾ | 1⅝ | ½ | 2⅝ | 9/16 | 3⅞ | 1 3/16 | ⅜ | ⅞ | 1⅝ |
| 1½ | 3 | 1 13/16 | ½ | 2 13/16 | ⅝ | 4¼ | 1¼ | ⅜ | 15/16 | 1 13/16 |

## Connecting Rod Stub End, for Crank Pin. Box End with Wedge Adjustment
*(Continued)*

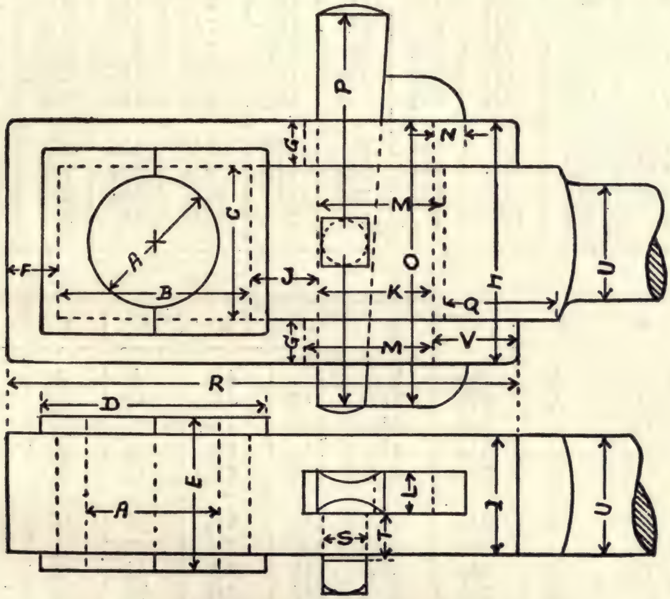
| A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 5/8 | 3 1/4 | 1 15/16 | 9/16 | 3 1/16 | 11/16 | 4 5/8 | 1 3/8 | 7/16 | 1 | 1 15/16 |
| 1 3/4 | 3 7/16 | 2 1/16 | 5/8 | 3 5/16 | 3/4 | 4 15/16 | 1 7/16 | 7/16 | 1 1/8 | 2 1/16 |
| 1 7/8 | 3 5/8 | 2 1/4 | 5/8 | 3 1/2 | 3/4 | 5 1/8 | 1 1/2 | 7/16 | 1 3/16 | 2 1/4 |
| 2 | 3 7/8 | 2 3/8 | 11/16 | 3 3/4 | 13/16 | 5 1/2 | 1 5/8 | 1/2 | 1 1/4 | 2 3/8 |
| 2 1/8 | 4 1/16 | 2 1/2 | 3/4 | 4 | 7/8 | 5 13/16 | 1 3/4 | 1/2 | 1 5/16 | 2 1/2 |
| 2 1/4 | 4 1/4 | 2 5/8 | 3/4 | 4 1/8 | 7/8 | 6 | 1 13/16 | 1/2 | 1 3/8 | 2 5/8 |
| 2 3/8 | 4 3/8 | 2 3/4 | 13/16 | 4 3/8 | 15/16 | 6 1/4 | 1 7/8 | 1/2 | 1 3/8 | 2 3/4 |
| 2 1/2 | 4 9/16 | 2 7/8 | 7/8 | 4 5/8 | 1 | 6 9/16 | 2 | 1/2 | 1 7/16 | 2 7/8 |
| 2 5/8 | 4 3/4 | 3 | 7/8 | 4 3/4 | 1 | 6 3/4 | 2 1/8 | 1/2 | 1 1/2 | 3 |
| 2 3/4 | 4 7/8 | 3 1/8 | 15/16 | 5 | 1 1/16 | 7 | 2 3/16 | 1/2 | 1 1/2 | 3 1/8 |
| 2 7/8 | 5 1/16 | 3 1/4 | 15/16 | 5 1/8 | 1 1/16 | 7 3/16 | 2 1/4 | 1/2 | 1 9/16 | 3 1/4 |
| 3 | 5 1/4 | 3 3/8 | 1 | 5 3/8 | 1 1/8 | 7 1/2 | 2 3/8 | 9/16 | 1 5/8 | 3 3/8 |
| 3 1/4 | 5 3/4 | 3 5/8 | 1 1/16 | 5 3/4 | 1 1/4 | 8 1/4 | 2 5/8 | 9/16 | 1 3/4 | 3 5/8 |
| 3 1/2 | 6 1/8 | 4 | 1 3/16 | 6 3/8 | 1 3/8 | 8 7/8 | 2 13/16 | 9/16 | 1 7/8 | 4 |
| 3 3/4 | 6 5/8 | 4 1/4 | 1 1/4 | 6 3/4 | 1 1/2 | 9 5/8 | 3 | 9/16 | 2 | 4 1/4 |
| 4 | 7 | 4 1/2 | 1 3/8 | 7 1/4 | 1 5/8 | 10 1/4 | 3 1/4 | 5/8 | 2 1/8 | 4 1/2 |
| 4 1/4 | 7 1/2 | 4 3/4 | 1 7/16 | 7 5/8 | 1 11/16 | 10 7/8 | 3 1/2 | 5/8 | 2 1/4 | 4 3/4 |
| 4 1/2 | 7 7/8 | 5 1/8 | 1 1/2 | 8 1/8 | 1 13/16 | 11 1/2 | 3 3/4 | 5/8 | 2 3/8 | 5 1/8 |
| 4 3/4 | 8 3/8 | 5 3/8 | 1 5/8 | 8 5/8 | 1 15/16 | 12 1/4 | 3 7/8 | 5/8 | 2 1/2 | 5 3/8 |
| 5 | 8 3/4 | 5 5/8 | 1 11/16 | 9 | 2 1/16 | 12 7/8 | 4 1/8 | 5/8 | 2 5/8 | 5 5/8 |
| 5 1/4 | 9 1/8 | 5 7/8 | 1 3/4 | 9 3/8 | 2 1/8 | 13 3/8 | 4 3/8 | 5/8 | 2 3/4 | 5 7/8 |
| 5 1/2 | 9 5/8 | 6 1/4 | 1 13/16 | 9 7/8 | 2 1/4 | 14 1/8 | 4 1/2 | 3/4 | 2 7/8 | 6 1/4 |
| 5 3/4 | 10 | 6 1/2 | 1 7/8 | 10 1/4 | 2 3/8 | 14 3/4 | 4 3/4 | 3/4 | 3 | 6 1/2 |
| 6 | 10 1/2 | 6 3/4 | 2 | 10 3/4 | 2 1/2 | 15 1/2 | 5 | 3/4 | 3 1/8 | 6 3/4 |

| A | L | M | N | O | P | Q | R | S | T | U |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1/2 | 1 3/8 | 2 7/16 | 5/32 | 5/16 | 5/32 | 1 3/8 | 7/8 | 3/16 | 1/4 |
| 1 1/8 | 9/16 | 1 1/2 | 2 11/16 | 5/32 | 5/16 | 5/32 | 1 9/16 | 1 | 3/16 | 1/4 |
| 1 1/4 | 5/8 | 1 5/8 | 2 15/16 | 3/16 | 3/8 | 3/16 | 1 3/4 | 1 1/8 | 1/4 | 5/16 |
| 1 3/8 | 11/16 | 1 3/4 | 3 1/8 | 3/16 | 3/8 | 3/16 | 1 7/8 | 1 3/16 | 1/4 | 5/16 |
| 1 1/2 | 3/4 | 1 7/8 | 3 3/8 | 3/16 | 3/8 | 3/16 | 2 1/16 | 1 5/16 | 1/4 | 3/8 |
| 1 5/8 | 13/16 | 2 | 3 5/8 | 3/16 | 7/16 | 3/16 | 2 1/4 | 1 7/16 | 5/16 | 3/8 |
| 1 3/4 | 7/8 | 2 1/8 | 3 15/16 | 1/4 | 7/16 | 1/4 | 2 7/16 | 1 9/16 | 5/16 | 7/16 |
| 1 7/8 | 15/16 | 2 1/4 | 4 1/8 | 1/4 | 7/16 | 1/4 | 2 9/16 | 1 5/8 | 3/8 | 7/16 |
| 2 | 1 | 2 3/8 | 4 3/8 | 1/4 | 1/2 | 1/4 | 2 3/4 | 1 3/4 | 3/8 | 1/2 |
| 2 1/8 | 1 | 2 1/2 | 4 9/16 | 5/16 | 1/2 | 1/4 | 2 7/8 | 1 7/8 | 3/8 | 1/2 |
| 2 1/4 | 1 1/8 | 2 5/8 | 4 3/4 | 5/16 | 1/2 | 1/4 | 3 1/16 | 1 15/16 | 3/8 | 1/2 |
| 2 3/8 | 1 1/8 | 2 3/4 | 4 7/8 | 5/16 | 9/16 | 1/4 | 3 3/16 | 2 | 3/8 | 1/2 |
| 2 1/2 | 1 1/4 | 2 7/8 | 5 1/16 | 5/16 | 9/16 | 1/4 | 3 5/16 | 2 1/8 | 7/16 | 1/2 |
| 2 5/8 | 1 1/4 | 3 | 5 3/8 | 5/16 | 9/16 | 5/16 | 3 1/2 | 2 1/4 | 7/16 | 5/8 |
| 2 3/4 | 1 3/8 | 3 1/8 | 5 1/2 | 5/16 | 5/8 | 5/16 | 3 5/8 | 2 5/16 | 7/16 | 5/8 |

## Connecting Rod Stub End, for Crank Pin. Box End with Wedge Adjustment
*(Continued)*

| A | L | M | N | O | P | Q | R | S | T | U |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 7/8 | 1 3/8 | 3 1/4 | 5 11/16 | 5/16 | 5/8 | 5/16 | 3 3/4 | 2 3/8 | 7/16 | 5/8 |
| 3 | 1 1/2 | 3 1/2 | 5 7/8 | 3/8 | 5/8 | 5/16 | 3 7/8 | 2 1/2 | 1/2 | 5/8 |
| 3 1/4 | 1 5/8 | 3 3/4 | 6 3/8 | 3/8 | 11/16 | 5/16 | 4 1/4 | 2 11/16 | 1/2 | 11/16 |
| 3 1/2 | 1 3/4 | 4 1/8 | 6 7/8 | 7/16 | 3/4 | 3/8 | 4 1/2 | 2 7/8 | 1/2 | 3/4 |
| 3 3/4 | 1 7/8 | 4 3/8 | 7 3/8 | 1/2 | 7/8 | 3/8 | 4 7/8 | 3 1/8 | 1/2 | 3/4 |
| 4 | 2 | 4 3/4 | 7 3/4 | 1/2 | 15/16 | 3/8 | 5 1/8 | 3 5/16 | 5/8 | 13/16 |
| 4 1/4 | 2 1/8 | 5 | 8 1/4 | 9/16 | 1 | 3/8 | 5 1/2 | 3 1/2 | 5/8 | 7/8 |
| 4 1/2 | 2 1/4 | 5 1/4 | 8 3/4 | 9/16 | 1 1/16 | 7/16 | 5 7/8 | 3 3/4 | 5/8 | 15/16 |
| 4 3/4 | 2 3/8 | 5 1/2 | 9 1/4 | 5/8 | 1 1/8 | 7/16 | 6 1/8 | 4 | 5/8 | 1 |
| 5 | 2 1/2 | 5 7/8 | 9 5/8 | 5/8 | 1 1/4 | 7/16 | 6 1/2 | 4 1/8 | 5/8 | 1 1/16 |
| 5 1/4 | 2 5/8 | 6 1/8 | 10 | 11/16 | 1 5/16 | 7/16 | 6 3/4 | 4 3/8 | 3/4 | 1 1/16 |
| 5 1/2 | 2 3/4 | 6 3/8 | 10 5/8 | 11/16 | 1 3/8 | 1/2 | 7 1/8 | 4 9/16 | 3/4 | 1 1/8 |
| 5 3/4 | 2 7/8 | 6 3/4 | 11 | 3/4 | 1 7/16 | 1/2 | 7 3/8 | 4 3/4 | 3/4 | 1 1/8 |
| 6 | 3 | 7 | 11 1/2 | 3/4 | 1 1/2 | 1/2 | 7 3/4 | 5 | 3/4 | 1 1/4 |

## Connecting Rod Stub End, for Crank Pin. Strap Joint with Gib and Key




| A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 5/8 | 1 3/16 | 2 | 1 3/8 | 7/16 | 3/8 | 1 15/16 | 1 | 1/2 | 7/8 | 5/16 |
| 1 1/8 | 1 13/16 | 1 5/16 | 2 3/16 | 1 1/2 | 7/16 | 3/8 | 2 1/16 | 1 1/8 | 9/16 | 1 | 5/16 |
| 1 1/4 | 2 | 1 7/16 | 2 7/16 | 1 5/8 | 1/2 | 7/16 | 2 5/16 | 1 3/16 | 5/8 | 1 1/8 | 3/8 |
| 1 3/8 | 2 1/8 | 1 5/8 | 2 9/16 | 1 3/4 | 9/16 | 1/2 | 2 5/8 | 1 5/16 | 11/16 | 1 1/4 | 3/8 |
| 1 1/2 | 2 5/16 | 1 3/4 | 2 13/16 | 1 7/8 | 5/8 | 1/2 | 2 3/4 | 1 3/8 | 3/4 | 1 3/8 | 7/16 |

## Connecting Rod Stub End, for Crank Pin. Strap Joint with Gib and Key

*(Continued)*

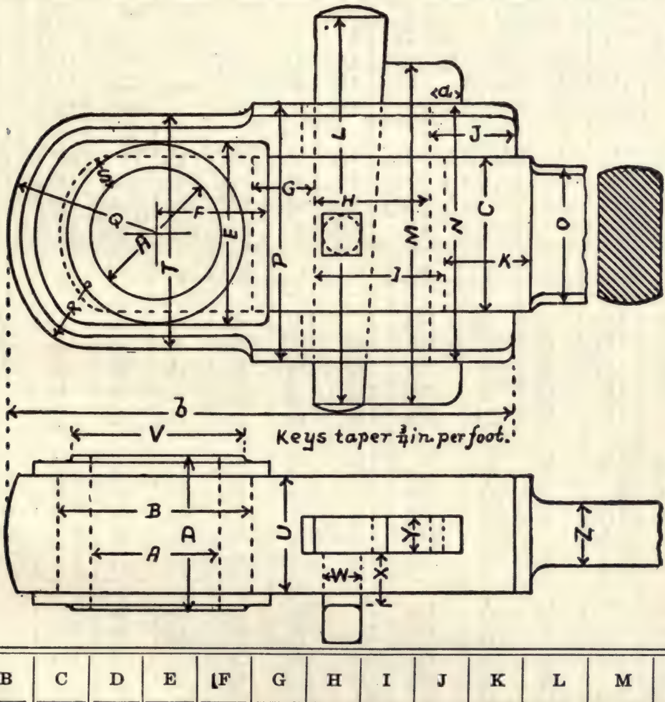
| A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 5/8 | 2 1/2 | 1 7/8 | 3 | 2 | 5/8 | 9/16 | 3 | 1 1/2 | 13/16 | 1 7/16 | 7/16 |
| 1 3/4 | 2 11/16 | 2 | 3 3/16 | 2 1/8 | 11/16 | 9/16 | 3 1/8 | 1 5/8 | 7/8 | 1 9/16 | 1/2 |
| 1 7/8 | 2 13/16 | 2 1/8 | 3 3/8 | 2 1/4 | 3/4 | 5/8 | 3 3/8 | 1 11/16 | 15/16 | 1 11/16 | 1/2 |
| 2 | 3 | 2 5/16 | 3 9/16 | 2 3/8 | 13/16 | 11/16 | 3 11/16 | 1 13/16 | 1 | 1 13/16 | 9/16 |
| 2 1/8 | 3 3/16 | 2 7/16 | 3 3/4 | 2 1/2 | 13/16 | 3/4 | 3 15/16 | 1 15/16 | 1 1/16 | 1 15/16 | 9/16 |
| 2 1/4 | 3 3/8 | 2 9/16 | 4 | 2 5/8 | 7/8 | 3/4 | 4 1/16 | 2 | 1 1/8 | 2 1/16 | 5/8 |
| 2 3/8 | 3 9/16 | 2 3/4 | 4 3/16 | 2 3/4 | 15/16 | 3/4 | 4 1/4 | 2 1/8 | 1 3/16 | 2 3/16 | 5/8 |
| 2 1/2 | 3 11/16 | 2 13/16 | 4 5/16 | 2 7/8 | 1 | 13/16 | 4 7/16 | 2 1/4 | 1 1/4 | 2 5/16 | 5/8 |
| 2 5/8 | 3 7/8 | 3 | 4 9/16 | 3 | 1 | 13/16 | 4 5/8 | 2 3/8 | 1 5/16 | 2 7/16 | 11/16 |
| 2 3/4 | 4 | 3 1/8 | 4 11/16 | 3 1/8 | 1 1/16 | 7/8 | 4 7/8 | 2 7/16 | 1 3/8 | 2 1/2 | 11/16 |
| 2 7/8 | 4 3/16 | 3 1/4 | 4 7/8 | 3 1/4 | 1 1/8 | 15/16 | 5 1/8 | 2 9/16 | 1 7/16 | 2 5/8 | 3/4 |
| 3 | 4 3/8 | 3 3/8 | 5 1/8 | 3 1/2 | 1 1/8 | 15/16 | 5 1/4 | 2 5/8 | 1 1/2 | 2 3/4 | 3/4 |
| 3 1/4 | 4 3/4 | 3 11/16 | 5 1/2 | 3 3/4 | 1 1/4 | 1 | 5 11/16 | 2 7/8 | 1 5/8 | 3 | 13/16 |
| 3 1/2 | 5 | 3 15/16 | 5 3/4 | 4 1/8 | 1 5/16 | 1 1/8 | 6 3/16 | 3 | 1 3/4 | 3 1/4 | 7/8 |
| 3 3/4 | 5 3/8 | 4 1/4 | 6 3/16 | 4 3/8 | 1 7/16 | 1 1/8 | 6 1/2 | 3 1/4 | 1 7/8 | 3 1/2 | 15/16 |
| 4 | 5 3/4 | 4 1/2 | 6 9/16 | 4 3/4 | 1 1/2 | 1 1/4 | 7 | 3 1/2 | 2 | 3 3/4 | 1 |
| 4 1/4 | 6 1/8 | 4 3/4 | 6 15/16 | 5 | 1 5/8 | 1 3/8 | 7 1/2 | 3 3/4 | 2 1/8 | 4 | 1 1/16 |
| 4 1/2 | 6 5/8 | 5 | 7 1/2 | 5 1/4 | 1 11/16 | 1 7/16 | 7 7/8 | 4 | 2 1/4 | 4 1/4 | 1 1/8 |
| 4 3/4 | 7 | 5 3/8 | 7 7/8 | 5 1/2 | 1 3/4 | 1 1/2 | 8 3/8 | 4 3/8 | 2 3/8 | 4 1/2 | 1 3/16 |
| 5 | 7 3/8 | 5 5/8 | 8 1/4 | 5 7/8 | 1 7/8 | 1 5/8 | 8 7/8 | 4 5/8 | 2 1/2 | 4 3/4 | 1 1/4 |
| 5 1/4 | 7 3/4 | 5 7/8 | 8 5/8 | 6 1/8 | 2 | 1 11/16 | 9 1/4 | 4 7/8 | 2 5/8 | 4 7/8 | 1 5/16 |
| 5 1/2 | 8 1/4 | 6 1/4 | 9 1/4 | 6 3/8 | 2 1/16 | 1 13/16 | 9 7/8 | 5 1/4 | 2 3/4 | 5 1/8 | 1 3/8 |
| 5 3/4 | 8 5/8 | 6 1/2 | 9 5/8 | 6 3/4 | 2 1/8 | 1 7/8 | 10 1/4 | 5 1/2 | 2 7/8 | 5 3/8 | 1 7/16 |
| 6 | 9 | 6 3/4 | 10 | 7 | 2 1/4 | 2 | 10 3/4 | 5 3/4 | 3 | 5 5/8 | 1 1/2 |

| A | M | N | O | P | Q | R | S | T | U | V |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 3/16 | 2 11/16 | 3 | 1 | 4 3/16 | 5/16 | 7/16 | 7/8 | 3/4 |
| 1 1/8 | 1 1/8 | 3/16 | 2 13/16 | 3 3/8 | 1 1/8 | 4 5/8 | 3/8 | 1/2 | 1 | 13/16 |
| 1 1/4 | 1 1/4 | 1/4 | 3 3/16 | 3 3/4 | 1 3/16 | 5 1/8 | 3/8 | 1/2 | 1 1/16 | 7/8 |
| 1 3/8 | 1 3/8 | 1/4 | 3 5/8 | 4 1/8 | 1 1/4 | 5 5/8 | 1/2 | 9/16 | 1 3/16 | 1 |
| 1 1/2 | 1 1/2 | 5/16 | 3 3/4 | 4 1/2 | 1 3/8 | 6 1/8 | 1/2 | 9/16 | 1 5/16 | 1 1/16 |
| 1 5/8 | 1 5/8 | 5/16 | 4 1/8 | 4 7/8 | 1 1/2 | 6 1/2 | 1/2 | 5/8 | 1 3/8 | 1 1/8 |
| 1 3/4 | 1 3/4 | 3/8 | 4 1/4 | 5 1/4 | 1 9/16 | 7 | 1/2 | 11/16 | 1 1/2 | 1 3/16 |
| 1 7/8 | 1 7/8 | 3/8 | 4 5/8 | 5 5/8 | 1 11/16 | 7 7/16 | 1/2 | 3/4 | 1 5/8 | 1 1/4 |
| 2 | 2 | 7/16 | 5 1/16 | 6 | 1 3/4 | 7 15/16 | 5/8 | 3/4 | 1 3/4 | 1 5/16 |
| 2 1/8 | 2 1/8 | 1/2 | 5 7/16 | 6 3/8 | 1 7/8 | 8 1/2 | 5/8 | 7/8 | 1 13/16 | 1 7/16 |
| 2 1/4 | 2 1/4 | 1/2 | 5 9/16 | 6 3/4 | 2 | 8 15/16 | 5/8 | 7/8 | 1 15/16 | 1 1/2 |
| 2 3/8 | 2 3/8 | 1/2 | 5 3/4 | 7 1/8 | 2 1/8 | 9 3/8 | 5/8 | 7/8 | 2 | 1 9/16 |
| 2 1/2 | 2 1/2 | 1/2 | 6 1/16 | 7 1/2 | 2 1/8 | 9 7/8 | 5/8 | 1 | 2 1/8 | 1 11/16 |
| 2 5/8 | 2 5/8 | 9/16 | 6 1/4 | 7 7/8 | 2 1/4 | 10 3/8 | 5/8 | 1 | 2 1/4 | 1 3/4 |
| 2 3/4 | 2 3/4 | 9/16 | 6 5/8 | 8 1/4 | 2 5/16 | 10 11/16 | 5/8 | 1 | 2 3/8 | 1 13/16 |

STRAP JOINT WITH GIB AND KEY—(*Continued*)

| A | M | N | O | P | Q | R | S | T | U | V |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 7/8 | 2 7/8 | 5/8 | 7 | 8 5/8 | 2 3/8 | 11 1/4 | 5/8 | 1 1/8 | 2 7/16 | 1 7/8 |
| 3 | 3 | 5/8 | 7 1/8 | 9 | 2 1/2 | 11 11/16 | 5/8 | 1 1/8 | 2 9/16 | 2 |
| 3 1/4 | 3 1/4 | 11/16 | 7 11/16 | 9 3/4 | 2 11/16 | 12 11/16 | 5/8 | 1 3/16 | 2 3/4 | 2 1/8 |
| 3 1/2 | 3 1/2 | 3/4 | 8 7/16 | 10 1/2 | 2 7/8 | 13 9/16 | 3/4 | 1 3/16 | 2 7/8 | 2 5/16 |
| 3 3/4 | 3 3/4 | 13/16 | 8 3/4 | 11 1/4 | 3 1/8 | 14 9/16 | 3/4 | 1 1/4 | 3 1/8 | 2 1/2 |
| 4 | 4 | 7/8 | 9 1/2 | 12 | 3 1/4 | 15 1/2 | 3/4 | 1 3/8 | 3 3/8 | 2 5/8 |
| 4 1/4 | 4 1/4 | 15/16 | 10 1/4 | 12 3/4 | 3 1/2 | 16 5/8 | 3/4 | 1 1/2 | 3 1/2 | 2 3/4 |
| 4 1/2 | 4 1/2 | 1 | 10 3/4 | 13 1/2 | 3 5/8 | 17 3/4 | 7/8 | 1 11/16 | 3 3/4 | 2 15/16 |
| 4 3/4 | 4 3/4 | 1 | 11 3/8 | 14 1/4 | 3 7/8 | 18 3/4 | 7/8 | 1 3/4 | 3 7/8 | 3 1/8 |
| 5 | 5 | 1 1/16 | 12 1/8 | 15 | 4 | 19 3/4 | 7/8 | 1 7/8 | 4 | 3 1/4 |
| 5 1/4 | 5 1/4 | 1 1/8 | 12 5/8 | 15 3/4 | 4 1/4 | 20 5/8 | 7/8 | 2 | 4 1/4 | 3 3/8 |
| 5 1/2 | 5 1/2 | 1 1/8 | 13 1/2 | 16 1/2 | 4 3/8 | 21 11/16 | 7/8 | 2 3/8 | 4 3/8 | 3 1/2 |
| 5 3/4 | 5 3/4 | 1 3/16 | 14 | 17 1/4 | 4 1/2 | 22 5/8 | 7/8 | 2 9/16 | 4 5/8 | 3 5/8 |
| 6 | 6 | 1 1/4 | 14 3/4 | 18 | 4 5/8 | 23 5/8 | 1 | 2 3/4 | 4 3/4 | 3 3/4 |

CONNECTING ROD STUB END, FOR CRANK PIN. STRAP JOINT WITH GIB AND KEY




| A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 5/8 | 1 3/16 | 1 3/8 | 1 9/16 | 1 | 1/2 | 7/8 | 1 | 3/4 | 13/16 | 3 | 2 3/4 | 2 | 1 1/8 |
| 1 1/8 | 1 13/16 | 1 5/16 | 1 1/2 | 1 11/16 | 1 1/8 | 9/16 | 1 | 1 1/8 | 13/16 | 7/8 | 3 3/8 | 3 | 2 1/4 | 1 1/4 |
| 1 1/4 | 2 | 1 7/16 | 1 5/8 | 1 7/8 | 1 3/16 | 5/8 | 1 1/8 | 1 1/4 | 7/8 | 15/16 | 3 7/8 | 3 1/8 | 2 3/8 | 1 3/8 |
| 1 3/8 | 2 1/8 | 1 5/8 | 1 3/4 | 2 | 1 1/4 | 11/16 | 1 1/4 | 1 3/8 | 1 | 1 1/16 | 4 1/4 | 3 9/16 | 2 11/16 | 1 1/2 |
| 1 1/2 | 2 5/16 | 1 3/4 | 1 7/8 | 2 1/8 | 1 3/8 | 3/4 | 1 3/8 | 1 1/2 | 1 1/16 | 1 1/8 | 4 3/4 | 3 15/16 | 2 15/16 | 1 5/8 |

STRAP JOINT WITH GIB AND KEY—(*Continued*)

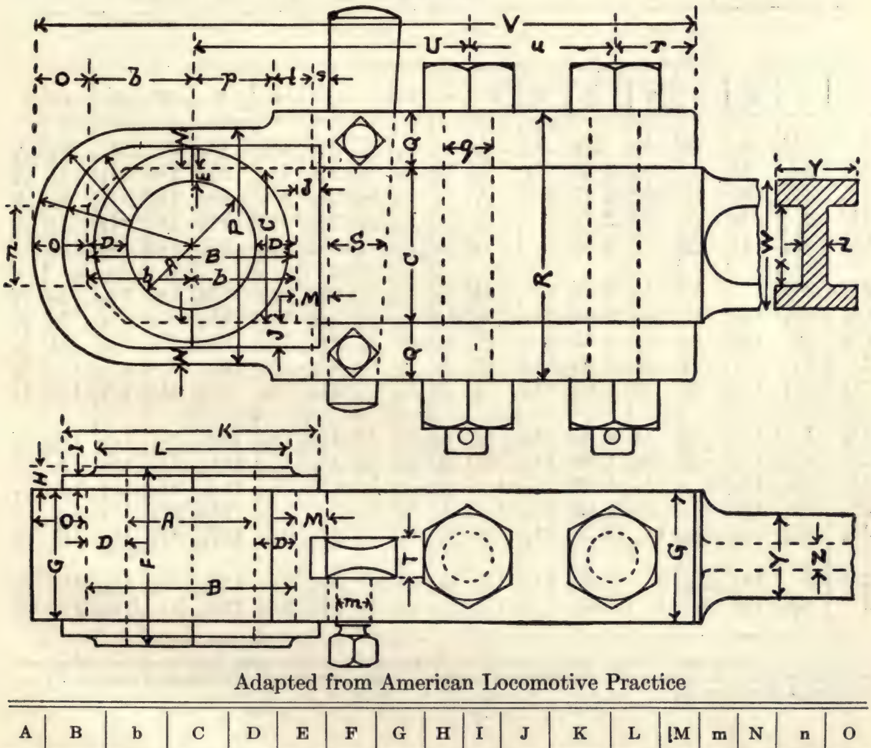
| A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 5/8 | 2 1/2 | 1 7/8 | 2 | 2 5/16 | 1 7/16 | 13/16 | 1 7/16 | 1 5/8 | 1 1/8 | 1 3/16 | 5 1/8 | 4 5/16 | 3 3/16 | 1 3/4 |
| 1 3/4 | 2 11/16 | 2 | 2 1/8 | 2 1/2 | 1 9/16 | 7/8 | 1 9/16 | 1 3/4 | 1 3/16 | 1 1/4 | 5 5/8 | 4 11/16 | 3 7/16 | 1 7/8 |
| 1 7/8 | 2 13/16 | 2 1/8 | 2 1/4 | 2 5/8 | 1 11/16 | 15/16 | 1 11/16 | 1 7/8 | 1 1/4 | 1 5/16 | 6 | 4 15/16 | 3 11/16 | 2 |
| 2 | 3 | 2 5/16 | 2 3/8 | 2 13/16 | 1 3/4 | 1 | 1 13/16 | 2 | 1 5/16 | 1 3/8 | 6 1/2 | 5 3/8 | 4 | 2 1/8 |
| 2 1/8 | 3 3/16 | 2 7/16 | 2 1/2 | 2 15/16 | 1 7/8 | 1 1/16 | 1 15/16 | 2 1/8 | 1 7/16 | 1 9/16 | 7 | 5 1/2 | 4 1/8 | 2 1/4 |
| 2 1/4 | 3 3/8 | 2 9/16 | 2 5/8 | 3 1/8 | 2 | 1 1/8 | 2 1/16 | 2 1/4 | 1 1/2 | 1 5/8 | 7 3/8 | 5 7/8 | 4 3/8 | 2 3/8 |
| 2 3/8 | 3 9/16 | 2 3/4 | 2 3/4 | 3 1/4 | 2 1/16 | 1 3/16 | 2 3/16 | 2 3/8 | 1 9/16 | 1 11/16 | 7 3/4 | 6 5/16 | 4 11/16 | 2 1/2 |
| 2 1/2 | 3 11/16 | 2 13/16 | 2 7/8 | 3 7/16 | 2 1/8 | 1 1/4 | 2 5/16 | 2 1/2 | 1 11/16 | 1 13/16 | 8 1/4 | 6 5/8 | 5 | 2 5/8 |
| 2 5/8 | 3 7/8 | 3 | 3 | 3 9/16 | 2 1/4 | 1 5/16 | 2 7/16 | 2 5/8 | 1 3/4 | 1 7/8 | 8 3/4 | 6 15/16 | 5 3/16 | 2 3/4 |
| 2 3/4 | 4 | 3 1/8 | 3 1/8 | 3 3/4 | 2 5/16 | 1 3/8 | 2 1/2 | 2 3/4 | 1 13/16 | 1 15/16 | 9 1/4 | 7 5/16 | 5 7/16 | 2 7/8 |
| 2 7/8 | 4 3/16 | 3 1/4 | 3 1/4 | 3 7/8 | 2 3/8 | 1 7/16 | 2 5/8 | 2 7/8 | 1 7/8 | 2 | 9 1/2 | 7 9/16 | 5 11/16 | 3 |
| 3 | 4 3/8 | 3 3/8 | 3 1/2 | 4 | 2 1/2 | 1 1/2 | 2 3/4 | 3 | 2 | 2 1/8 | 10 | 7 15/16 | 5 15/16 | 3 1/8 |
| 3 1/4 | 4 3/4 | 3 11/16 | 3 3/4 | 4 3/8 | 2 11/16 | 1 5/8 | 3 | 3 1/4 | 2 1/8 | 2 1/4 | 10 3/4 | 8 3/4 | 6 1/2 | 3 3/8 |
| 3 1/2 | 5 | 3 15/16 | 4 1/8 | 4 11/16 | 2 15/16 | 1 3/4 | 3 1/4 | 3 1/2 | 2 5/16 | 2 1/2 | 11 1/2 | 9 1/4 | 7 | 3 11/16 |
| 3 3/4 | 5 3/8 | 4 1/4 | 4 3/8 | 5 | 3 1/8 | 1 7/8 | 3 1/2 | 3 3/4 | 2 1/2 | 2 11/16 | 12 1/4 | 9 15/16 | 7 7/16 | 4 |
| 4 | 5 3/4 | 4 1/2 | 4 3/4 | 5 1/4 | 3 1/4 | 2 | 3 3/4 | 4 | 2 5/8 | 2 13/16 | 13 | 10 9/16 | 7 15/16 | 4 1/4 |
| 4 1/4 | 6 1/8 | 4 3/4 | 5 | 5 5/8 | 3 1/2 | 2 1/8 | 4 | 4 1/4 | 2 3/4 | 2 15/16 | 13 3/4 | 11 5/16 | 8 7/16 | 4 1/2 |
| 4 1/2 | 6 5/8 | 5 | 5 1/4 | 5 7/8 | 3 3/4 | 2 1/4 | 4 1/4 | 4 1/2 | 2 15/16 | 3 1/8 | 14 1/2 | 11 15/16 | 8 15/16 | 4 3/4 |
| 4 3/4 | 7 | 5 3/8 | 5 1/2 | 6 1/4 | 4 | 2 3/8 | 4 1/2 | 4 3/4 | 3 1/8 | 3 5/16 | 15 1/4 | 12 1/2 | 9 3/8 | 5 |
| 5 | 7 3/8 | 5 5/8 | 5 7/8 | 6 1/2 | 4 1/4 | 2 1/2 | 4 3/4 | 5 | 3 1/4 | 3 7/16 | 16 | 13 1/4 | 9 7/8 | 5 3/8 |
| 5 1/4 | 7 3/4 | 5 7/8 | 6 1/8 | 6 7/8 | 4 3/8 | 2 5/8 | 4 7/8 | 5 1/4 | 3 3/8 | 3 9/16 | 17 | 14 | 10 3/8 | 5 5/8 |
| 5 1/2 | 8 1/4 | 6 1/4 | 6 3/8 | 7 1/4 | 4 9/16 | 2 3/4 | 5 1/8 | 5 1/2 | 3 1/2 | 3 11/16 | 17 3/4 | 14 3/4 | 10 7/8 | 5 7/8 |
| 4 3/4 | 8 5/8 | 6 1/2 | 6 3/4 | 7 1/2 | 4 3/4 | 2 7/8 | 5 3/8 | 5 3/4 | 3 5/8 | 3 13/16 | 18 1/2 | 15 1/4 | 11 3/8 | 6 1/4 |
| 6 | 9 | 6 3/4 | 7 | 7 3/4 | 5 | 3 | 5 5/8 | 6 | 3 3/4 | 3 15/16 | 19 1/4 | 15 7/8 | 11 7/8 | 6 1/2 |

| A | P | Q | R | S | T | U | V | W | X | Y | Z | a | b |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 1/16 | 1 3/16 | 1/2 | 1/4 | 1 15/16 | 1 | 1 3/8 | 5/16 | 1/2 | 5/16 | 1/2 | 3/16 | 4 1/8 |
| 1 1/8 | 2 5/16 | 1 3/8 | 9/16 | 1/4 | 2 1/16 | 1 1/8 | 1 9/16 | 3/8 | 9/16 | 5/16 | 9/16 | 3/16 | 4 21/32 |
| 1 1/4 | 2 7/16 | 1 1/2 | 5/8 | 5/16 | 2 5/16 | 1 3/16 | 1 3/4 | 3/8 | 9/16 | 3/8 | 5/8 | 1/4 | 5 1/8 |
| 1 3/8 | 2 3/4 | 1 5/8 | 11/16 | 5/16 | 2 1/2 | 1 5/16 | 1 7/8 | 1/2 | 5/8 | 3/8 | 11/16 | 1/4 | 5 5/8 |
| 1 1/2 | 3 | 1 3/4 | 3/4 | 3/8 | 2 3/4 | 1 3/8 | 2 1/16 | 1/2 | 5/8 | 7/16 | 3/4 | 5/16 | 6 3/32 |
| 1 5/8 | 3 1/4 | 1 7/8 | 13/16 | 3/8 | 3 | 1 1/2 | 2 1/4 | 1/2 | 11/16 | 7/16 | 13/16 | 5/16 | 6 1/2 |
| 1 3/4 | 3 1/2 | 2 | 7/8 | 7/16 | 3 1/4 | 1 5/8 | 2 7/16 | 1/2 | 3/4 | 1/2 | 7/8 | 3/8 | 6 31/32 |
| 1 7/8 | 3 3/4 | 2 3/16 | 15/16 | 7/16 | 3 1/2 | 1 11/16 | 2 9/16 | 1/2 | 3/4 | 1/2 | 15/16 | 3/8 | 7 15/32 |
| 2 | 4 1/16 | 2 5/16 | 1 | 1/2 | 3 11/16 | 1 13/16 | 2 3/4 | 5/8 | 13/16 | 9/16 | 1 | 7/16 | 7 15/16 |
| 2 1/8 | 4 3/16 | 2 7/16 | 1 1/16 | 1/2 | 3 15/16 | 1 15/16 | 2 7/8 | 5/8 | 7/8 | 9/16 | 1 | 1/2 | 8 15/32 |
| 2 1/4 | 4 7/16 | 2 5/8 | 1 1/8 | 9/16 | 4 3/16 | 2 | 3 1/16 | 5/8 | 7/8 | 5/8 | 1 1/8 | 1/2 | 9 |
| 2 3/8 | 4 3/4 | 2 3/4 | 1 3/16 | 9/16 | 4 3/8 | 2 1/8 | 3 3/16 | 5/8 | 15/16 | 5/8 | 1 1/8 | 1/2 | 9 15/32 |
| 2 1/2 | 5 1/16 | 2 7/8 | 1 1/4 | 5/8 | 4 11/16 | 2 1/4 | 3 5/16 | 5/8 | 1 | 5/8 | 1 1/4 | 1/2 | 9 31/32 |
| 2 5/8 | 5 1/4 | 3 | 1 5/16 | 5/8 | 4 3/4 | 2 3/8 | 3 1/2 | 5/8 | 1 | 11/16 | 1 1/4 | 9/16 | 10 7/16 |
| 2 3/4 | 5 1/2 | 3 1/8 | 1 3/8 | 11/16 | 5 | 2 7/16 | 3 5/8 | 5/8 | 1 1/16 | 11/16 | 1 3/8 | 9/16 | 10 13/16 |
| 2 7/8 | 5 3/4 | 3 5/16 | 1 7/16 | 11/16 | 5 1/4 | 2 9/16 | 3 3/4 | 5/8 | 1 1/8 | 3/4 | 1 3/8 | 5/8 | 11 11/32 |
| 3 | 6 | 3 7/16 | 1 1/2 | 3/4 | 5 1/2 | 2 5/8 | 3 7/8 | 5/8 | 1 1/8 | 3/4 | 1 1/2 | 5/8 | 11 7/8 |
| 3 1/4 | 6 9/16 | 3 3/4 | 1 5/8 | 3/4 | 6 1/16 | 2 7/8 | 4 1/4 | 5/8 | 1 1/4 | 13/16 | 1 5/8 | 11/16 | 12 7/8 |
| 3 1/2 | 7 1/16 | 4 | 1 3/8 | 7/8 | 6 9/16 | 3 | 4 1/2 | 3/4 | 1 3/8 | 7/8 | 1 3/4 | 3/4 | 13 13/16 |
| 3 3/4 | 7 1/2 | 4 5/16 | 1 7/8 | 7/8 | 6 7/8 | 3 1/4 | 4 7/8 | 3/4 | 1 1/2 | 15/16 | 1 7/8 | 13/16 | 14 7/8 |

## Connecting Rod Stub End for Crank Pin. Strap Joint with Gib and Key (*Continued*)

| A | P | Q | R | S | T | U | V | W | X | Y | Z | a | b |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 8 | 4 9/16 | 2 | 1 | 7¼ | 3½ | 5⅛ | ¾ | 1⅝ | 1 | 2 | ⅞ | 15 13/16 |
| 4¼ | 8½ | 4⅞ | 2⅛ | 1 | 7¾ | 3¾ | 5½ | ¾ | 1 11/16 | 1 1/16 | 2⅛ | 15/16 | 16 13/16 |
| 4½ | 9 | 5⅛ | 2¼ | 1⅛ | 8¼ | 4 | 5⅞ | ⅞ | 1 13/16 | 1⅛ | 2¼ | 1 | 17⅞ |
| 4¾ | 9½ | 5 7/16 | 2⅜ | 1⅛ | 8¾ | 4⅜ | 6⅛ | ⅞ | 1 15/16 | 1 3/16 | 2⅜ | 1 | 18 15/16 |
| 5 | 10 | 5¾ | 2½ | 1¼ | 9⅛ | 4⅝ | 6½ | ⅞ | 2 1/16 | 1¼ | 2½ | 1 1/16 | 19 15/16 |
| 5¼ | 10½ | 6 | 2⅝ | 1¼ | 9⅝ | 4⅞ | 6¾ | ⅞ | 2 3/16 | 1 5/16 | 2⅝ | 1⅛ | 20¾ |
| 5½ | 11 | 6¼ | 2¾ | 1⅜ | 10 | 5¼ | 7⅛ | ⅞ | 2 5/16 | 1⅜ | 2¾ | 1⅛ | 21¾ |
| 5¾ | 11½ | 6⅝ | 2⅞ | 1⅜ | 10½ | 5½ | 7⅜ | ⅞ | 2 7/16 | 1 7/16 | 2⅞ | 1 3/16 | 22 13/16 |
| 6 | 12 | 6⅞ | 3 | 1½ | 11 | 5¾ | 7¾ | 1 | 2½ | 1½ | 3 | 1¼ | 23¾ |

## Connecting Rod Stub End for Crank Pin with Bolted Strap, Wedge Block and Key



Adapted from American Locomotive Practice

| A | B | b | C | D | E | F | G | H | I | J | K | L | M | m | N | n | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1⅝ | 13/16 | 1 3/16 | 5/16 | 3/32 | 1⅜ | 1 | 3/16 | ⅛ | 3/16 | 2 | 1½ | ¼ | ¼ | 5/16 | ⅝ | 7/16 |
| 1⅛ | 1.81 | .91 | 1.33 | .34 | .10 | 1½ | 1⅛ | 3/16 | ⅛ | .20 | 2.21 | 1 11/16 | ¼ | ¼ | ⅜ | 11/16 | ½ |
| 1¼ | 2.00 | 1.00 | 1.47 | .38 | .11 | 1⅝ | 1 3/16 | 7/32 | ⅛ | .21 | 2.42 | 1 13/16 | 5/16 | ¼ | ⅜ | ¾ | ½ |
| 1⅜ | 2.19 | 1.09 | 1.61 | .41 | .12 | 1¾ | 1 5/16 | 7/32 | ⅛ | .23 | 2.65 | 2 | 5/16 | 5/16 | 7/16 | 13/16 | 9/16 |
| 1½ | 2.38 | 1.19 | 1.75 | .44 | .12 | 1⅞ | 1⅜ | ¼ | ⅛ | .24 | 2.86 | 2⅛ | 5/16 | 5/16 | 7/16 | ⅞ | ⅝ |

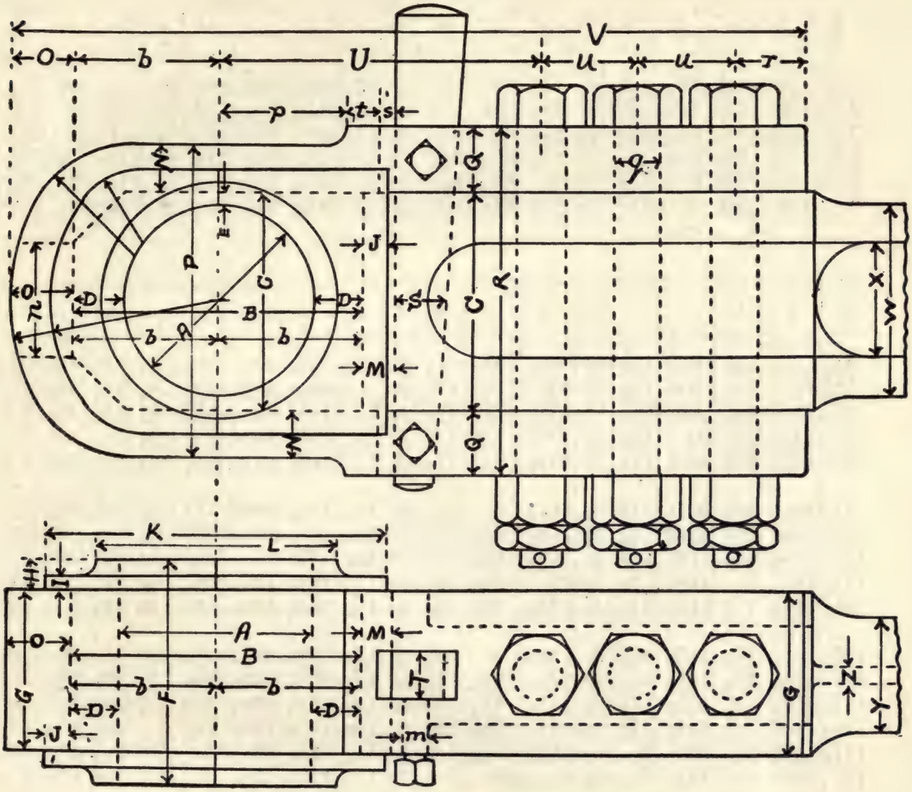
## Connecting Rod Stub End for Crank Pin with Bolted Strap, Wedge Block and Key—*Continued*

| A | B | b | C | D | E | F | G | H | I | J | K | L | M | m | N | n | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 5/8 | 2.56 | 1.28 | 1.89 | .47 | .13 | 2 | 1 1/2 | 1/4 | 1/8 | .26 | 3.08 | 2 1/4 | 3/8 | 5/16 | 1/2 | 15/16 | 11/16 |
| 1 3/4 | 2.75 | 1.38 | 2.03 | .50 | .14 | 2 1/8 | 1 5/8 | 1/4 | 3/16 | .27 | 3.29 | 2 7/16 | 3/8 | 3/8 | 1/2 | 1 | 11/16 |
| 1 7/8 | 2.94 | 1.47 | 2.17 | .53 | .15 | 2 1/4 | 1 11/16 | 7/32 | 3/16 | .28 | 3.50 | 2 5/8 | 3/8 | 3/8 | 9/16 | 1 1/8 | 3/4 |
| 2 | 3.13 | 1.56 | 2.31 | .56 | .16 | 2 3/8 | 1 13/16 | 9/32 | 3/16 | .30 | 3.73 | 2 3/4 | 3/8 | 3/8 | 5/8 | 1 3/16 | 13/16 |
| 2 1/8 | 3.31 | 1.66 | 2.45 | .59 | .16 | 2 1/2 | 1 15/16 | 9/32 | 3/16 | .31 | 3.93 | 2 15/16 | 7/16 | 3/8 | 5/8 | 1 1/4 | 13/16 |
| 2 1/4 | 3.50 | 1.75 | 2.59 | .63 | .17 | 2 5/8 | 2 | 5/16 | 3/16 | .32 | 4.14 | 3 1/16 | 7/16 | 3/8 | 11/16 | 1 5/16 | 7/8 |
| 2 3/8 | 3.69 | 1.84 | 2.73 | .66 | .18 | 2 3/4 | 2 1/8 | 5/16 | 3/16 | .34 | 4.37 | 3 1/4 | 7/16 | 3/8 | 11/16 | 1 3/8 | 15/16 |
| 2 1/2 | 3.88 | 1.94 | 2.88 | .69 | .19 | 2 7/8 | 2 1/4 | 5/16 | 1/4 | .35 | 4.58 | 3 3/8 | 1/2 | 3/8 | 3/4 | 1 7/16 | 15/16 |
| 2 5/8 | 4.06 | 2.03 | 3.02 | .72 | .20 | 3 | 2 3/8 | 5/16 | 1/4 | .37 | 4.80 | 3 9/16 | 1/2 | 7/16 | 3/4 | 1 1/2 | 1 |
| 2 3/4 | 4.25 | 2.13 | 3.16 | .75 | .20 | 3 1/8 | 2 7/16 | 11/32 | 1/4 | .38 | 5.00 | 3 11/16 | 1/2 | 7/16 | 13/16 | 1 5/8 | 1 1/16 |
| 2 7/8 | 4.44 | 2.22 | 3.30 | .78 | .21 | 3 1/4 | 2 9/16 | 11/32 | 1/4 | .39 | 5.22 | 3 7/8 | 9/16 | 7/16 | 13/16 | 1 11/16 | 1 1/16 |
| 3 | 4 5/8 | 2 5/16 | 3 7/16 | 13/16 | 7/32 | 3 1/2 | 2 5/8 | 7/16 | 1/4 | 13/32 | 5 7/16 | 4 | 9/16 | 1/2 | 7/8 | 1 3/4 | 1 1/8 |

| A | P | p | Q | q | R | r | S | s | T | t | U | u | V | W | X | Y | Z |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 13/16 | 5/8 | 7/16 | 3/8 | 2 1/16 | 5/8 | 7/16 | 1/8 | 5/16 | 5/16 | 2 1/4 | 1 1/8 | 5 1/8 | 1 | 5/8 | 5/8 | 3/16 |
| 1 1/8 | 2 1/16 | 11/16 | 1/2 | 1/2 | 2.33 | 3/4 | 1/2 | 1/8 | 5/16 | 3/8 | 2 1/2 | 1 1/4 | 5 15/16 | 1 1/8 | 3/4 | 11/16 | 3/16 |
| 1 1/4 | 2 1/4 | 13/16 | 1/2 | 5/8 | 2.47 | 1 | 9/16 | 1/8 | 3/8 | 3/8 | 2 11/16 | 1 1/2 | 6 11/16 | 1 1/4 | 13/16 | 3/4 | 3/16 |
| 1 3/8 | 2 1/2 | 7/8 | 9/16 | 5/8 | 2.74 | 1 | 5/8 | 1/8 | 7/16 | 7/16 | 2 15/16 | 1 1/2 | 7 1/8 | 1 3/8 | 15/16 | 3/4 | 3/16 |
| 1 1/2 | 2 5/8 | 15/16 | 9/16 | 5/8 | 2.88 | 1 | 5/8 | 1/8 | 7/16 | 7/16 | 3 1/8 | 1 1/2 | 7 7/16 | 1 1/2 | 1 1/16 | 13/16 | 1/4 |
| 1 5/8 | 2 7/8 | 1 | 5/8 | 5/8 | 3.14 | 1 | 11/16 | 1/8 | 1/2 | 1/2 | 3 3/8 | 1 1/2 | 7 7/8 | 1 5/8 | 1 3/16 | 7/8 | 1/4 |
| 1 3/4 | 3 1/16 | 1 1/16 | 11/16 | 5/8 | 3.41 | 1 | 3/4 | 1/8 | 1/2 | 1/2 | 3 9/16 | 1 1/2 | 8 1/8 | 1 3/4 | 1 1/4 | 7/8 | 1/4 |
| 1 7/8 | 3 5/16 | 1 1/8 | 3/4 | 5/8 | 3.67 | 1 | 13/16 | 1/8 | 9/16 | 9/16 | 3 13/16 | 1 1/2 | 8 1/2 | 1 7/8 | 1 3/8 | 15/16 | 1/4 |
| 2 | 3 9/16 | 1 1/4 | 13/16 | 3/4 | 3.94 | 1 1/8 | 7/8 | 3/16 | 9/16 | 5/8 | 4 1/16 | 1 3/4 | 9 5/16 | 2 | 1 1/2 | 1 | 1/4 |
| 2 1/8 | 3 11/16 | 1 5/16 | 13/16 | 3/4 | 4.08 | 1 1/8 | 7/8 | 3/16 | 5/8 | 5/8 | 4 1/4 | 1 3/4 | 9 5/8 | 2 1/8 | 1 9/16 | 1 1/8 | 1/4 |
| 2 1/4 | 4 | 1 3/8 | 7/8 | 7/8 | 4.34 | 1 3/8 | 15/16 | 3/16 | 5/8 | 11/16 | 4 1/2 | 1 7/8 | 10 3/8 | 2 1/4 | 1 9/16 | 1 3/16 | 1/4 |
| 2 3/8 | 4 1/8 | 1 7/16 | 15/16 | 7/8 | 4.61 | 1 3/8 | 15/16 | 3/16 | 11/16 | 11/16 | 4 3/4 | 1 7/8 | 10 3/4 | 2 3/8 | 1 5/8 | 1 5/16 | 1/4 |
| 2 1/2 | 4 3/8 | 1 1/2 | 1 | 7/8 | 4.88 | 1 3/8 | 1 | 3/16 | 11/16 | 3/4 | 4 15/16 | 1 7/8 | 11 1/16 | 2 1/2 | 1 11/16 | 1 7/16 | 5/16 |
| 2 5/8 | 4 9/16 | 1 5/8 | 1 | 7/8 | 5.02 | 1 3/8 | 1 | 3/16 | 3/4 | 3/4 | 5 3/16 | 1 7/8 | 11 1/2 | 2 5/8 | 1 3/4 | 1 9/16 | 5/16 |
| 2 3/4 | 4 13/16 | 1 11/16 | 1 1/16 | 1 | 5.29 | 1 1/2 | 1 1/8 | 3/16 | 3/4 | 13/16 | 5 3/8 | 2 1/8 | 12 3/16 | 2 3/4 | 1 3/4 | 1 11/16 | 5/16 |
| 2 7/8 | 5 | 1 3/4 | 1 1/16 | 1 | 5.43 | 1 1/2 | 1 3/16 | 3/16 | 13/16 | 13/16 | 5 5/8 | 2 1/8 | 12 1/2 | 2 7/8 | 1 13/16 | 1 3/4 | 5/16 |
| 3 | 5 3/16 | 1 13/16 | 1 1/8 | 1 | 5 11/16 | 1 1/2 | 1 1/4 | 3/16 | 13/16 | 7/8 | 5 13/16 | 2 1/8 | 12 7/8 | 3 | 1 7/8 | 1 7/8 | 5/16 |

Distance U is subject to slight correction due to fractional quantities being expressed in the nearest working fraction. In no case will the difference exceed 1/16 inch. Fractional differences in column V may be adjusted in column U.

## Connecting Rod Stub End for Crank Pin, with Bolted Strap, Wedge Block, and Key




Adapted from American Locomotive Practice

| A | B | b | C | D | E | F | G | H | I | J | K | L | M | m | N | n | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 4 5/8 | 2 5/16 | 3 7/16 | 13/16 | 7/32 | 3 1/2 | 2 5/8 | 7/16 | 1/4 | 13/32 | 5 7/16 | 4 | 9/16 | 1/2 | 7/8 | 1 3/4 | 1 1/8 |
| 3 1/4 | 5 | 2 1/2 | 3 3/4 | 7/8 | 1/4 | 3 3/4 | 2 13/16 | 15/32 | 1/4 | 7/16 | 5 7/8 | 4 1/4 | 5/8 | 1/2 | 15/16 | 1 7/8 | 1 1/4 |
| 3 1/2 | 5 3/8 | 2 11/16 | 4 | 15/16 | 1/4 | 4 1/8 | 3 | 9/16 | 5/16 | 7/16 | 6 1/4 | 4 9/16 | 5/8 | 1/2 | 1 | 2 | 1 5/16 |
| 3 3/4 | 5 3/4 | 2 7/8 | 4 1/4 | 1 | 1/4 | 4 3/8 | 3 3/16 | 19/32 | 5/16 | 1/2 | 6 3/4 | 4 7/8 | 11/16 | 1/2 | 1 1/16 | 2 1/8 | 1 3/8 |
| 4 | 6 | 3 | 4 1/2 | 1 | 1/4 | 4 3/4 | 3 7/16 | 21/32 | 5/16 | 9/16 | 7 1/8 | 5 1/8 | 3/4 | 1/2 | 1 1/8 | 2 1/4 | 1 1/2 |
| 4 1/4 | 6 1/2 | 3 1/4 | 4 3/4 | 1 1/8 | 1/4 | 5 | 3 5/8 | 11/16 | 5/16 | 9/16 | 7 5/8 | 5 7/16 | 3/4 | 1/2 | 1 1/8 | 2 3/8 | 1 5/8 |
| 4 1/2 | 6 7/8 | 3 7/16 | 5 1/8 | 1 3/16 | 5/16 | 5 1/4 | 3 13/16 | 23/32 | 3/8 | 9/16 | 8 | 5 11/16 | 3/4 | 1/2 | 1 3/16 | 2 5/8 | 1 13/16 |
| 4 3/4 | 7 1/8 | 3 9/16 | 5 3/8 | 1 3/16 | 5/16 | 5 1/2 | 4 | 3/4 | 3/8 | 5/8 | 8 3/8 | 6 | 13/16 | 1/2 | 1 1/4 | 2 3/4 | 1 7/8 |
| 5 | 7 1/2 | 3 3/4 | 5 5/8 | 1 1/4 | 5/16 | 5 7/8 | 4 1/4 | 13/16 | 3/8 | 5/8 | 8 3/4 | 6 1/4 | 7/8 | 1/2 | 1 3/8 | 2 7/8 | 1 7/8 |
| 5 1/4 | 7 7/8 | 3 15/16 | 5 7/8 | 1 5/16 | 5/16 | 6 1/8 | 4 3/8 | 7/8 | 3/8 | 5/8 | 9 1/8 | 6 9/16 | 7/8 | 1/2 | 1 3/8 | 3 | 2 |
| 5 1/2 | 8 1/4 | 4 1/8 | 6 1/8 | 1 3/8 | 5/16 | 6 3/8 | 4 5/8 | 7/8 | 3/8 | 11/16 | 9 5/8 | 6 13/16 | 15/16 | 1/2 | 1 7/16 | 3 1/8 | 2 1/16 |
| 5 3/4 | 8 5/8 | 4 5/16 | 6 1/2 | 1 7/16 | 3/8 | 6 3/4 | 4 13/16 | 31/32 | 7/16 | 11/16 | 10 | 7 1/16 | 15/16 | 1/2 | 1 7/16 | 3 1/4 | 2 1/8 |
| 6 | 9 | 4 1/2 | 6 3/4 | 1 1/2 | 3/8 | 7 | 5 | 1 | 7/16 | 3/4 | 10 1/2 | 7 3/8 | 1 | 5/8 | 1 1/2 | 3 3/8 | 2 1/4 |
| 6 1/4 | 9 1/4 | 4 5/8 | 7 | 1 1/2 | 3/8 | 7 1/4 | 5 1/4 | 1 | 7/16 | 3/4 | 10 3/4 | 7 3/4 | 1 | 5/8 | 1 1/2 | 3 1/2 | 2 5/16 |
| 6 1/2 | 9 1/2 | 4 3/4 | 7 1/4 | 1 1/2 | 3/8 | 7 5/8 | 5 1/2 | 1 1/16 | 7/16 | 3/4 | 11 | 8 | 1 1/8 | 5/8 | 1 9/16 | 3 5/8 | 2 3/8 |

## Connecting Rod Stub End for Crank Pin, with Bolted Strap, Wedge Block, and Key—*Continued*

| A | B | b | C | D | E | F | G | H | I | J | K | L | M | m | N | n | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6¾ | 9⅞ | 4 15/16 | 7⅝ | 1 9/16 | 7/16 | 7⅞ | 5⅝ | 1⅛ | ½ | 13/16 | 11½ | 8¼ | 1⅛ | ⅝ | 1⅝ | 3⅞ | 2½ |
| 7 | 10⅛ | 5 1/16 | 7⅞ | 1 9/16 | 7/16 | 8⅛ | 5⅞ | 1⅛ | ½ | 13/16 | 11¾ | 8½ | 1¼ | ⅝ | 1⅝ | 4 | 2 9/16 |
| 7¼ | 10½ | 5¼ | 8⅛ | 1⅝ | 7/16 | 8½ | 6⅛ | 1 3/16 | ½ | 13/16 | 12⅛ | 8¾ | 1¼ | ⅝ | 1 11/16 | 4⅛ | 2⅝ |
| 7½ | 10¾ | 5⅜ | 8⅜ | 1⅝ | 7/16 | 8¾ | 6⅜ | 1 3/16 | ½ | 13/16 | 12⅜ | 9⅛ | 1¼ | ⅝ | 1¾ | 4¼ | 2 11/16 |
| 7¾ | 11⅛ | 5 9/16 | 8¾ | 1 11/16 | ½ | 9 | 6½ | 1¼ | 9/16 | ⅞ | 12⅞ | 9½ | 1⅜ | ⅝ | 1 13/16 | 4⅜ | 2¾ |
| 8 | 11⅜ | 5 11/16 | 9 | 1 11/16 | ½ | 9⅜ | 6¾ | 1 5/16 | 9/16 | ⅞ | 13⅛ | 9¾ | 1⅜ | ¾ | 1⅞ | 4½ | 2⅞ |

| A | B | b | C | D | E | F | G | H | I | J | K | L | M | m | N | n | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8¼ | 11⅝ | 5 13/16 | 9¼ | 1 11/16 | ½ | 9⅝ | 6⅞ | 1⅜ | 9/16 | ⅞ | 13⅜ | 10 | 1⅜ | ¾ | 1⅞ | 4⅝ | 2⅞ |
| 8½ | 12 | 6 | 9½ | 1¾ | ½ | 10 | 7⅛ | 1 7/16 | 9/16 | 1 | 14 | 10¼ | 1⅜ | ¾ | 1 15/16 | 4¾ | 3 |
| 8¾ | 12¼ | 6⅛ | 9¾ | 1¾ | ½ | 10¼ | 7⅜ | 1 7/16 | 9/16 | 1 | 14¼ | 10½ | 1½ | ¾ | 1 15/16 | 4⅞ | 3 1/16 |
| 9 | 12½ | 6¼ | 10 | 1¾ | ½ | 10½ | 7½ | 1½ | 9/16 | 1 | 14½ | 10⅞ | 1½ | ¾ | 2 | 5 | 3⅛ |
| 9¼ | 12¾ | 6⅜ | 10¼ | 1¾ | ½ | 10¾ | 7¾ | 1½ | 9/16 | 1 | 14¾ | 11⅛ | 1½ | ¾ | 2 | 5⅛ | 3 3/16 |
| 9½ | 13⅛ | 6 9/16 | 10½ | 1 13/16 | ½ | 11⅛ | 8 | 1 9/16 | 9/16 | 1⅛ | 15⅜ | 11⅜ | 1⅝ | ¾ | 2 1/16 | 5¼ | 3¼ |
| 9¾ | 13⅜ | 6 11/16 | 10⅞ | 1 13/16 | 9/16 | 11⅜ | 8⅛ | 1⅝ | ⅝ | 1⅛ | 15⅝ | 11⅝ | 1⅝ | ¾ | 2⅛ | 5 7/16 | 3⅜ |
| 10 | 13⅝ | 6 13/16 | 11⅛ | 1 13/16 | 9/16 | 11⅝ | 8⅜ | 1⅝ | ⅝ | 1⅛ | 15⅞ | 12 | 1¾ | ⅞ | 2⅛ | 5⅝ | 3½ |
| 10¼ | 14 | 7 | 11⅜ | 1⅞ | 9/16 | 12 | 8⅝ | 1 11/16 | ⅝ | 1⅛ | 16¼ | 12¼ | 1¾ | ⅞ | 2 3/16 | 5¾ | 3½ |
| 10½ | 14¼ | 7⅛ | 11⅝ | 1⅞ | 9/16 | 12¼ | 8¾ | 1¾ | ⅝ | 1 3/16 | 16⅝ | 12⅝ | 1¾ | ⅞ | 2¼ | 5⅞ | 3 9/16 |
| 10¾ | 14½ | 7¼ | 11⅞ | 1⅞ | 9/16 | 12½ | 9 | 1¾ | 11/16 | 1 3/16 | 16⅞ | 12⅞ | 1⅞ | ⅞ | 2¼ | 6 | 3⅝ |
| 11 | 14¾ | 7⅜ | 12⅛ | 1⅞ | 9/16 | 12⅞ | 9¼ | 1 13/16 | 11/16 | 1 3/16 | 17⅛ | 13⅛ | 1⅞ | ⅞ | 2⅜ | 6⅛ | 3¾ |
| 11¼ | 15⅛ | 7 9/16 | 12⅜ | 1 15/16 | 9/16 | 13⅛ | 9½ | 1 13/16 | 11/16 | 1 3/16 | 17½ | 13⅜ | 1⅞ | ⅞ | 2⅜ | 6¼ | 3¾ |
| 11½ | 15⅜ | 7 11/16 | 12¾ | 1 15/16 | ⅝ | 13½ | 9⅝ | 1 15/16 | 11/16 | 1¼ | 17⅞ | 13⅝ | 1⅞ | 1 | 2 7/16 | 6⅜ | 3⅞ |
| 11¾ | 15¾ | 7⅞ | 13 | 2 | ⅝ | 13¾ | 9⅞ | 1 15/16 | ¾ | 1¼ | 18¼ | 14 | 2 | 1 | 2 7/16 | 6½ | 3 15/16 |
| 12 | 16 | 8 | 13¼ | 2 | ⅝ | 14 | 10 | 2 | ¾ | 1¼ | 18½ | 14¼ | 2 | 1 | 2½ | 6⅝ | 4 |

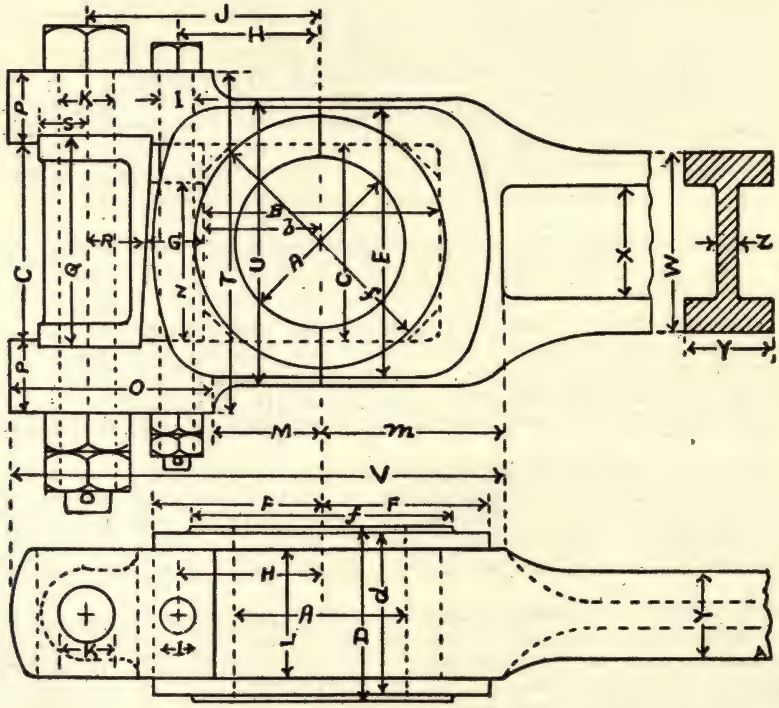
| A | P | p | Q | q | R | r | S | s | T | t | U | u | V | W | X | Y | Z |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 5 3/16 | 1 13/16 | 1⅛ | ¾ | 5 11/16 | 1⅛ | 1¼ | 3/16 | 13/16 | ⅞ | 5½ | 1¾ | 13 9/16 | 3 | 1⅞ | 1⅞ | 5/16 |
| 3¼ | 5⅝ | 2 1/16 | 1¼ | ⅞ | 6¼ | 1⅜ | 1¼ | 3/16 | ⅞ | ⅞ | 6 | 1⅞ | 14⅞ | 3¼ | 2 | 2 | 5/16 |
| 3½ | 6 | 2⅛ | 1 5/16 | ⅞ | 6⅝ | 1⅜ | 1 5/16 | ¼ | 15/16 | 15/16 | 6¼ | 1⅞ | 15⅜ | 3½ | 2 3/16 | 2 3/16 | ⅜ |
| 3¾ | 6⅜ | 2⅜ | 1 7/16 | 1 | 7⅛ | 1½ | 1 5/16 | ¼ | 1 | 15/16 | 6⅝ | 2⅛ | 16⅝ | 3¾ | 2⅜ | 2⅜ | ⅜ |
| 4 | 6¾ | 2½ | 1½ | 1 | 7½ | 1½ | 1⅜ | ¼ | 1 1/16 | 1 | 7 | 2⅛ | 17¼ | 4 | 2½ | 2½ | ⅜ |
| 4¼ | 7 | 2 11/16 | 1½ | 1⅛ | 7¾ | 1¾ | 1⅜ | 5/16 | 1⅛ | 1 | 7 7/16 | 2⅜ | 18 13/16 | 4¼ | 2⅝ | 2⅝ | ⅜ |
| 4½ | 7½ | 2 13/16 | 1 9/16 | 1⅛ | 8¼ | 1¾ | 1 7/16 | 5/16 | 1 3/16 | 1 1/16 | 7 11/16 | 2⅜ | 19 7/16 | 4½ | 2¾ | 2¾ | 7/16 |
| 4¾ | 7⅞ | 2 15/16 | 1 11/16 | 1¼ | 8¾ | 1⅞ | 1 7/16 | ⅜ | 1¼ | 1 1/16 | 8 | 2½ | 20 5/16 | 4¾ | 2⅞ | 2⅞ | 7/16 |
| 5 | 8⅜ | 3⅛ | 1 13/16 | 1¼ | 9¼ | 1⅞ | 1½ | ⅜ | 1¼ | 1⅛ | 8⅜ | 2½ | 20⅞ | 5 | 3 | 3 | 7/16 |
| 5¼ | 8⅝ | 3¼ | 1 13/16 | 1⅜ | 9½ | 2⅛ | 1½ | 7/16 | 1⅜ | 1⅛ | 8 13/16 | 2⅞ | 22⅝ | 5¼ | 3⅛ | 3⅛ | 7/16 |
| 5½ | 9 | 3 7/16 | 1 15/16 | 1⅜ | 10 | 2⅛ | 1 9/16 | 7/16 | 1 7/16 | 1 3/16 | 9⅛ | 2⅞ | 23 3/16 | 5½ | 3¼ | 3¼ | ½ |
| 5¾ | 9⅜ | 3 9/16 | 1 15/16 | 1½ | 10⅜ | 2¼ | 1 9/16 | ½ | 1½ | 1 3/16 | 9 7/16 | 3 | 24⅛ | 5¾ | 3⅜ | 3⅜ | ½ |
| 6 | 9¾ | 3¾ | 2 | 1½ | 10¾ | 2¼ | 1⅝ | ½ | 1 9/16 | 1¼ | 9¾ | 3 | 24¾ | 6 | 3½ | 3½ | ½ |
| 6¼ | 10 | 3⅞ | 2 1/16 | 1⅝ | 11⅛ | 2½ | 1⅝ | ½ | 1⅝ | 1¼ | 10⅛ | 3¼ | 26 1/16 | 6¼ | 3⅝ | 3⅝ | ½ |
| 6½ | 10⅜ | 4 1/16 | 2⅛ | 1⅝ | 11½ | 2½ | 1¾ | ½ | 1⅝ | 1 5/16 | 10½ | 3¼ | 26⅝ | 6½ | 3¾ | 3¾ | 9/16 |

Connecting Rod Stub End for Crank Pin, with Bolted Strap, Wedge Block, and Key—*Continued*

| A | P | p | Q | q | R | r | S | s | T | t | U | u | V | W | X | Y | Z |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6¾ | 10⅞ | 4¼ | 2 3/16 | 1¾ | 12 | 2⅝ | 1¾ | ½ | 1¾ | 1 5/16 | 10 13/16 | 3½ | 27 15/16 | 6¾ | 3⅞ | 3⅞ | 9/16 |
| 7 | 11⅛ | 4 7/16 | 2¼ | 1¾ | 12⅜ | 2⅝ | 1⅞ | ½ | 1¾ | 1⅜ | 11¼ | 3½ | 28½ | 7 | 4 | 4 | 9/16 |
| 7¼ | 11½ | 4⅝ | 2 5/16 | 1⅞ | 12¾ | 2⅞ | 1⅞ | ½ | 1 13/16 | 1⅜ | 11⅝ | 3¾ | 29⅞ | 7¼ | 4⅛ | 4⅛ | 9/16 |
| 7½ | 12¼ | 4 11/16 | 2⅜ | 1⅞ | 13⅛ | 2⅞ | 2 | ½ | 1 13/16 | 1 7/16 | 11⅞ | 3¾ | 30 5/16 | 7½ | 4⅜ | 4⅜ | ⅝ |
| 7¾ | 12⅜ | 5 | 2 7/16 | 2 | 13⅝ | 3 | 2 | ½ | 1 13/16 | 1 7/16 | 12 3/16 | 3⅞ | 31¼ | 7¾ | 4½ | 4½ | ⅝ |
| 8 | 12¾ | 5 1/16 | 2½ | 2 | 14 | 3 | 2 1/6 | ½ | 2 | 1½ | 12½ | 3⅞ | 31 15/16 | 8 | 4⅝ | 4¾ | ⅝ |

| A | P | p | Q | q | R | r | S | s | T | t | U | u | V | W | X | Y | Z |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8¼ | 13 | 5 3/16 | 2 9/16 | 2 | 14⅜ | 3 | 2⅛ | ½ | 2 | 1½ | 12 11/16 | 3⅞ | 32⅛ | 8¼ | 4¾ | 4¾ | ⅝ |
| 8½ | 13⅜ | 5 5/16 | 2⅝ | 2¼ | 14¾ | 3⅜ | 2 3/16 | ½ | 2 | 1 9/16 | 13 5/16 | 4⅜ | 34 7/16 | 8½ | 5 | 5 | ¾ |
| 8¾ | 13⅝ | 5 9/16 | 2⅝ | 2¼ | 15 | 3⅜ | 2¼ | ½ | 2⅛ | 1 9/16 | 13⅝ | 4⅜ | 34 15/16 | 8¾ | 5⅛ | 5⅛ | ¾ |
| 9 | 24 | 5½ | 2 11/16 | 2¼ | 15⅜ | 3⅜ | 2 5/16 | ⅝ | 2¼ | 1⅝ | 14 | 4⅜ | 35½ | 9 | 5¼ | 5¼ | ¾ |
| 9¼ | 14¼ | 5⅝ | 2¾ | 2¼ | 15¾ | 3⅜ | 2⅜ | ⅝ | 2¼ | 1⅝ | 14⅛ | 4⅜ | 35 13/16 | 9¼ | 5⅜ | 5⅜ | ¾ |
| 9½ | 14⅝ | 5⅞ | 2 13/16 | 2½ | 16⅛ | 3¾ | 2 7/16 | ⅝ | 2⅜ | 1 11/16 | 14⅞ | 4¾ | 37 15/16 | 9½ | 5½ | 5½ | 13/16 |
| 9¾ | 15⅛ | 6 | 2⅞ | 2½ | 16⅝ | 3¾ | 2½ | ⅝ | 2⅜ | 1 11/16 | 15 | 4¾ | 38 5/16 | 9¾ | 5⅝ | 5¾ | 13/16 |
| 10 | 15⅜ | 6 3/16 | 2 15/16 | 2½ | 17 | 3¾ | 2 9/16 | ⅝ | 2½ | 1¾ | 15⅜ | 4¾ | 38 15/16 | 10 | 5¾ | 5⅞ | 13/16 |
| 10¼ | 15¾ | 6⅜ | 3 | 2½ | 17⅜ | 3¾ | 2 9/16 | ⅝ | 2½ | 1¾ | 15 9/16 | 4¾ | 39 5/16 | 10¼ | 5⅞ | 6 | 13/16 |
| 10½ | 16⅛ | 6 7/16 | 3 | 2¾ | 17⅝ | 4⅛ | 2⅝ | ⅝ | 2⅝ | 1 13/16 | 16⅛ | 5¼ | 41 7/16 | 10½ | 6 | 6¼ | ⅞ |
| 10¾ | 16⅜ | 6 11/16 | 3⅛ | 2¾ | 18⅛ | 4⅛ | 2⅝ | ⅝ | 2⅝ | 1 13/16 | 16⅜ | 5¼ | 41⅞ | 10¾ | 6⅛ | 6⅜ | ⅞ |
| 11 | 16⅞ | 6¾ | 3 3/16 | 2¾ | 18½ | 4⅛ | 2¾ | ⅝ | 2¾ | 1⅞ | 16⅝ | 5¼ | 42⅜ | 11 | 6¼ | 6½ | ⅞ |
| 11¼ | 17⅛ | 6 13/16 | 3 3/16 | 2¾ | 18¾ | 4⅛ | 2¾ | ¾ | 2¾ | 1⅞ | 16⅞ | 5¼ | 42 13/16 | 11¼ | 6½ | 6⅝ | ⅞ |
| 11½ | 17⅝ | 6 15/16 | 3¼ | 3 | 19¼ | 4½ | 2⅞ | ¾ | 2⅞ | 1⅞ | 17½ | 5¾ | 45 1/16 | 11½ | 6¾ | 6¾ | 15/16 |
| 11¾ | 17⅞ | 7⅛ | 3¼ | 3 | 19½ | 4½ | 2⅞ | ¾ | 2⅞ | 2 | 17¾ | 5¾ | 45 9/16 | 11¾ | 6⅞ | 6⅞ | 15/16 |
| 12 | 18¼ | 7¼ | 3⅜ | 3 | 20 | 4½ | 3 | ¾ | 3 | 2 | 18 | 5¾ | 46 | 12 | 7 | 7 | 1 |

## Connecting Rod Stub End for Crank Pin. Forked Design with Back Block, Adjusting Wedge and Liner




Adapted from American Locomotive Practice

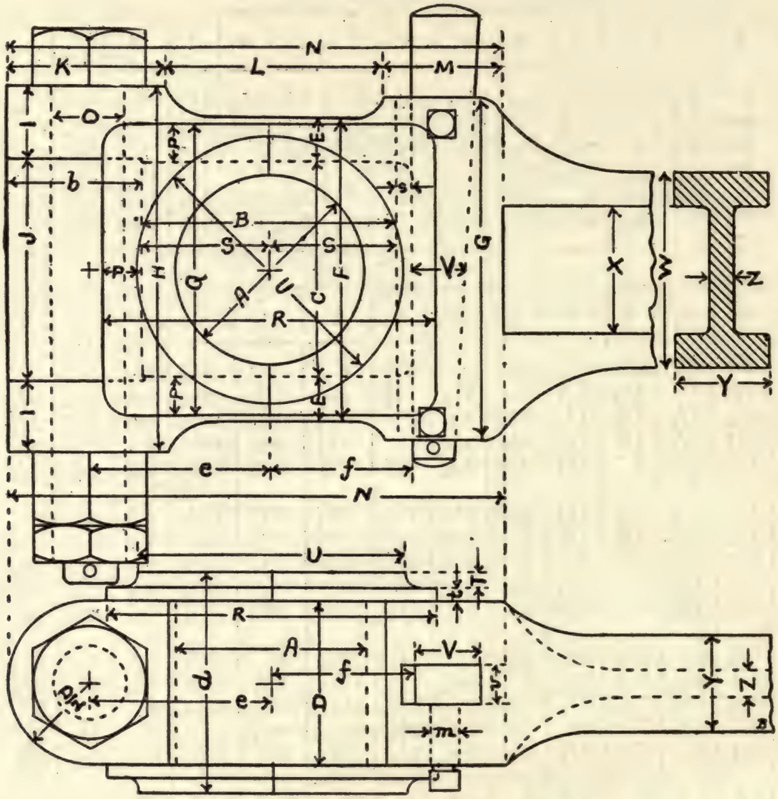
| A | B | b | C | D | d | E | F | f | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | $4\frac{3}{8}$ | $2\frac{3}{16}$ | $3\frac{3}{8}$ | $3\frac{1}{2}$ | 3 | $4\frac{1}{2}$ | $2\frac{7}{8}$ | 4 | $1\frac{1}{8}$ | $2\frac{11}{16}$ | $\frac{5}{8}$ | $4\frac{5}{16}$ | 1 | $2\frac{5}{8}$ | $1\frac{3}{4}$ |
| $3\frac{1}{4}$ | $4\frac{3}{4}$ | $2\frac{3}{8}$ | $3\frac{5}{8}$ | $3\frac{3}{4}$ | $3\frac{1}{4}$ | $4\frac{5}{8}$ | $3\frac{1}{8}$ | $4\frac{1}{4}$ | $1\frac{3}{16}$ | $2\frac{7}{8}$ | $\frac{5}{8}$ | $4\frac{5}{8}$ | 1 | $2\frac{13}{16}$ | $1\frac{7}{8}$ |
| $3\frac{1}{2}$ | 5 | $2\frac{1}{2}$ | $3\frac{7}{8}$ | $4\frac{1}{8}$ | $3\frac{5}{8}$ | $5\frac{1}{8}$ | $3\frac{3}{8}$ | $4\frac{5}{8}$ | $1\frac{1}{4}$ | $3\frac{1}{16}$ | $\frac{5}{8}$ | $4\frac{15}{16}$ | $1\frac{1}{8}$ | 3 | $2\frac{1}{16}$ |
| $3\frac{3}{4}$ | $5\frac{3}{8}$ | $2\frac{11}{16}$ | $4\frac{1}{4}$ | $4\frac{3}{8}$ | $3\frac{3}{4}$ | $5\frac{1}{2}$ | $3\frac{5}{8}$ | 5 | $1\frac{5}{16}$ | $3\frac{1}{4}$ | $\frac{3}{4}$ | $5\frac{1}{4}$ | $1\frac{1}{4}$ | $3\frac{1}{4}$ | $2\frac{1}{4}$ |
| 4 | $5\frac{5}{8}$ | $2\frac{3}{6}$ | $4\frac{1}{2}$ | $4\frac{3}{4}$ | 4 | 6 | $3\frac{7}{8}$ | $5\frac{1}{4}$ | $1\frac{7}{16}$ | $3\frac{7}{16}$ | $\frac{3}{4}$ | $5\frac{9}{16}$ | $1\frac{3}{8}$ | $3\frac{3}{8}$ | $2\frac{7}{16}$ |
| $4\frac{1}{4}$ | 6 | 3 | $4\frac{3}{4}$ | 5 | $4\frac{3}{8}$ | $6\frac{1}{4}$ | $4\frac{1}{8}$ | $5\frac{5}{8}$ | $1\frac{1}{2}$ | $3\frac{5}{8}$ | $\frac{3}{4}$ | $5\frac{7}{8}$ | $1\frac{3}{8}$ | $3\frac{5}{8}$ | $2\frac{9}{16}$ |
| $4\frac{1}{2}$ | $6\frac{1}{4}$ | $3\frac{1}{8}$ | 5 | $5\frac{1}{4}$ | $4\frac{1}{2}$ | $6\frac{3}{4}$ | $4\frac{3}{8}$ | 6 | $1\frac{9}{16}$ | $3\frac{13}{16}$ | $\frac{3}{4}$ | $6\frac{3}{16}$ | $1\frac{1}{2}$ | $3\frac{13}{16}$ | $2\frac{3}{4}$ |
| $4\frac{3}{4}$ | $6\frac{5}{8}$ | $3\frac{5}{16}$ | $5\frac{3}{8}$ | $5\frac{1}{2}$ | $4\frac{3}{4}$ | $7\frac{1}{8}$ | $4\frac{5}{8}$ | $6\frac{1}{4}$ | $1\frac{5}{8}$ | 4 | $\frac{7}{8}$ | $6\frac{1}{2}$ | $1\frac{1}{2}$ | 4 | $2\frac{7}{8}$ |
| 5 | 7 | $3\frac{1}{2}$ | $5\frac{5}{8}$ | $5\frac{7}{8}$ | 5 | $7\frac{5}{8}$ | $4\frac{7}{8}$ | $6\frac{5}{8}$ | $1\frac{11}{16}$ | $4\frac{1}{4}$ | $\frac{7}{8}$ | $6\frac{13}{16}$ | $1\frac{5}{8}$ | $4\frac{3}{16}$ | $3\frac{1}{16}$ |
| $5\frac{1}{4}$ | $7\frac{1}{4}$ | $3\frac{5}{8}$ | $5\frac{7}{8}$ | $6\frac{1}{8}$ | $5\frac{1}{4}$ | $7\frac{7}{8}$ | $5\frac{1}{4}$ | 7 | $1\frac{3}{4}$ | $4\frac{7}{16}$ | $\frac{7}{8}$ | $7\frac{1}{16}$ | $1\frac{3}{4}$ | $4\frac{3}{8}$ | $3\frac{1}{4}$ |
| $5\frac{1}{2}$ | $7\frac{5}{8}$ | $3\frac{13}{16}$ | $6\frac{1}{8}$ | $6\frac{3}{8}$ | $5\frac{1}{2}$ | $8\frac{3}{8}$ | $5\frac{1}{2}$ | $7\frac{1}{4}$ | $1\frac{13}{16}$ | $4\frac{5}{8}$ | $\frac{7}{8}$ | $7\frac{3}{8}$ | $1\frac{7}{8}$ | $4\frac{5}{8}$ | $3\frac{7}{16}$ |
| $5\frac{3}{4}$ | 8 | 4 | $6\frac{1}{2}$ | $6\frac{3}{4}$ | $5\frac{3}{4}$ | $8\frac{3}{4}$ | $5\frac{3}{4}$ | $7\frac{5}{8}$ | $1\frac{15}{16}$ | $4\frac{13}{16}$ | 1 | $7\frac{11}{16}$ | $1\frac{7}{8}$ | $4\frac{13}{16}$ | $3\frac{9}{16}$ |
| 6 | $8\frac{1}{4}$ | $4\frac{1}{8}$ | $6\frac{3}{4}$ | 7 | 6 | $9\frac{1}{8}$ | 6 | 8 | 2 | 5 | 1 | 8 | 2 | 5 | $3\frac{3}{4}$ |
| $6\frac{1}{4}$ | $8\frac{1}{2}$ | $4\frac{1}{4}$ | 7 | $7\frac{1}{4}$ | $6\frac{1}{4}$ | $9\frac{1}{2}$ | $6\frac{1}{4}$ | $8\frac{1}{4}$ | $2\frac{1}{16}$ | $5\frac{3}{16}$ | 1 | $8\frac{3}{8}$ | 2 | $5\frac{1}{4}$ | $3\frac{15}{16}$ |
| $6\frac{1}{2}$ | $8\frac{3}{4}$ | $4\frac{3}{8}$ | $7\frac{1}{4}$ | $7\frac{5}{8}$ | $6\frac{5}{8}$ | $9\frac{3}{4}$ | $6\frac{1}{2}$ | $8\frac{5}{8}$ | $2\frac{1}{8}$ | $5\frac{3}{8}$ | 1 | $8\frac{11}{16}$ | $2\frac{1}{8}$ | $5\frac{1}{2}$ | $4\frac{1}{16}$ |

## Connecting Rod Stub End for Crank Pin. Forked Design with Back Block, Adjusting Wedge and Liner—*Continued*

| A | B | b | C | D | d | E | F | f | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 3/4 | 9 | 4 1/2 | 7 1/2 | 7 7/8 | 6 7/8 | 10 1/8 | 6 3/4 | 9 | 2 3/16 | 5 5/8 | 1 1/8 | 9 | 2 1/8 | 5 3/4 | 4 1/4 |
| 7 | 9 1/8 | 4 9/16 | 7 3/4 | 8 1/8 | 7 1/8 | 10 3/8 | 7 | 9 1/4 | 2 1/4 | 5 13/16 | 1 1/8 | 9 3/8 | 2 1/4 | 6 | 4 3/8 |
| 7 1/4 | 9 3/8 | 4 11/16 | 8 | 8 1/2 | 7 3/8 | 10 5/8 | 7 1/4 | 9 5/8 | 2 5/16 | 6 | 1 1/8 | 9 3/4 | 2 1/4 | 6 3/16 | 4 9/16 |
| 7 1/2 | 9 5/8 | 4 13/16 | 8 1/4 | 8 3/4 | 7 5/8 | 11 | 7 1/2 | 10 | 2 3/8 | 6 3/16 | 1 1/8 | 10 1/16 | 2 3/8 | 6 7/16 | 4 3/4 |
| 7 3/4 | 9 7/8 | 4 15/16 | 8 1/2 | 9 | 7 7/8 | 11 1/4 | 7 3/4 | 10 1/4 | 2 7/16 | 6 7/16 | 1 1/4 | 10 7/16 | 2 3/8 | 6 5/8 | 4 7/8 |
| 8 | 10 | 5 | 8 3/4 | 9 3/8 | 8 1/4 | 11 1/2 | 8 | 10 1/2 | 2 1/2 | 6 5/8 | 1 1/4 | 10 3/4 | 2 1/2 | 6 7/8 | 5 |

| A | m | N | O | P | Q | R | S | T | U | V | W | X | Y | Z |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 3 1/8 | 2 3/4 | 3 7/8 | 1 5/16 | 3 3/4 | 1 | 7/8 | 6 | 4 7/8 | 8 3/4 | 3 3/8 | 1 7/8 | 2 | 3/8 |
| 3 1/4 | 3 3/8 | 3 | 4 1/8 | 1 7/16 | 4 | 1 1/8 | 15/16 | 6 1/2 | 5 5/16 | 9 3/8 | 3 9/16 | 2 1/16 | 2 1/16 | 3/8 |
| 3 1/2 | 3 5/8 | 3 3/16 | 4 7/16 | 1 1/2 | 4 3/8 | 1 3/16 | 1 | 6 7/8 | 5 11/16 | 10 1/8 | 3 13/16 | 2 1/4 | 2 3/16 | 7/16 |
| 3 3/4 | 3 15/16 | 3 7/16 | 4 11/16 | 1 5/8 | 4 5/8 | 1 1/4 | 1 | 7 1/2 | 6 1/8 | 10 7/8 | 4 | 2 3/8 | 2 1/4 | 7/16 |
| 4 | 4 3/16 | 3 5/8 | 5 | 1 11/16 | 4 7/8 | 1 5/16 | 1 1/8 | 7 7/8 | 6 9/16 | 11 5/8 | 4 1/4 | 2 9/16 | 2 5/16 | 7/16 |
| 4 1/4 | 4 1/2 | 3 7/8 | 5 1/4 | 1 13/16 | 5 3/16 | 1 3/8 | 1 1/4 | 8 3/8 | 6 15/16 | 12 5/16 | 4 7/16 | 2 3/4 | 2 3/8 | 1/2 |
| 4 1/2 | 4 3/4 | 4 1/8 | 5 1/2 | 1 15/16 | 5 1/2 | 1 1/2 | 1 5/16 | 8 7/8 | 7 3/8 | 13 | 4 11/16 | 2 15/16 | 2 1/2 | 1/2 |
| 4 3/4 | 5 | 4 3/8 | 5 3/4 | 2 | 5 3/4 | 1 9/16 | 1 3/8 | 9 3/8 | 7 13/16 | 13 5/8 | 4 7/8 | 3 1/8 | 2 9/16 | 1/2 |
| 5 | 5 1/4 | 4 9/16 | 6 | 2 1/8 | 6 1/8 | 1 5/8 | 1 1/2 | 9 7/8 | 8 3/16 | 14 15/16 | 5 1/8 | 3 5/16 | 2 11/16 | 1/2 |
| 5 1/4 | 5 9/16 | 4 13/16 | 6 3/8 | 2 3/16 | 6 3/8 | 1 11/16 | 1 1/2 | 10 1/4 | 8 5/8 | 15 3/16 | 5 3/8 | 3 1/2 | 2 3/4 | 9/16 |
| 5 1/2 | 5 13/16 | 5 | 6 5/8 | 2 5/16 | 6 11/16 | 1 3/4 | 1 5/8 | 10 3/4 | 9 | 15 7/8 | 5 9/16 | 3 5/8 | 2 13/16 | 9/16 |
| 5 3/4 | 6 1/8 | 5 1/4 | 6 7/8 | 2 3/8 | 7 | 1 3/4 | 1 11/16 | 11 1/4 | 9 7/16 | 16 9/16 | 5 3/4 | 3 13/16 | 2 7/8 | 9/16 |
| 6 | 6 3/8 | 5 1/2 | 7 1/8 | 2 1/2 | 7 1/4 | 2 | 1 3/4 | 11 3/4 | 9 7/8 | 17 1/4 | 6 | 4 | 3 | 5/8 |
| 6 1/4 | 6 5/8 | 5 3/4 | 7 7/16 | 2 5/8 | 7 1/2 | 2 1/16 | 1 13/16 | 12 1/4 | 10 1/4 | 18 | 6 1/4 | 4 1/8 | 3 1/8 | 5/8 |
| 6 1/2 | 6 15/16 | 6 | 7 3/4 | 2 11/16 | 7 3/4 | 2 3/16 | 1 7/8 | 12 5/8 | 10 9/16 | 18 3/4 | 6 1/2 | 4 1/4 | 3 3/8 | 5/8 |
| 6 3/4 | 7 3/16 | 6 3/16 | 8 | 2 13/16 | 8 | 2 5/16 | 2 | 13 1/8 | 10 15/16 | 19 7/16 | 6 3/4 | 4 3/8 | 3 9/16 | 11/16 |
| 7 | 7 7/16 | 6 3/8 | 8 5/16 | 2 7/8 | 8 1/4 | 2 9/16 | 2 1/16 | 13 1/2 | 11 5/16 | 20 1/8 | 7 | 4 1/2 | 3 3/4 | 11/16 |
| 7 1/4 | 7 3/4 | 6 5/8 | 8 5/8 | 3 | 8 1/2 | 2 3/4 | 2 1/8 | 14 | 11 11/16 | 20 15/16 | 7 1/4 | 4 5/8 | 3 15/16 | 11/16 |
| 7 1/2 | 8 | 6 7/8 | 8 5/16 | 3 1/8 | 8 3/4 | 2 7/8 | 2 3/16 | 14 1/2 | 12 | 21 11/16 | 7 1/2 | 4 3/4 | 4 1/8 | 11/16 |
| 7 3/4 | 8 1/4 | 7 1/8 | 9 1/4 | 3 3/16 | 9 | 3 1/16 | 2 1/4 | 14 7/8 | 12 3/8 | 22 3/8 | 7 3/4 | 4 7/8 | 4 5/16 | 3/4 |
| 8 | 8 1/2 | 7 5/16 | 9 1/2 | 3 1/4 | 9 1/4 | 3 1/4 | 2 3/8 | 15 1/4 | 12 3/4 | 23 | 8 | 5 | 4 1/2 | 3/4 |

## Connecting Rod Stub End for Crank Pin. Forked Design with Back Block, Adjusting Key and Liner




Adapted from American Locomotive Practice

| A | B | b | C | D | d | E | e | F | f | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 4 | 2 1/8 | 3 3/8 | 2 1/2 | 3 1/2 | 11/16 | 2 7/8 | 4 3/4 | 2 1/4 | 5 3/8 | 5 3/4 | 1 1/8 | 3 1/2 | 2 1/2 | 3 3/8 | 1 7/8 |
| 3 1/4 | 4 3/8 | 2 5/16 | 3 11/16 | 2 3/4 | 3 3/4 | 3/4 | 3 1/8 | 5 3/16 | 2 7/16 | 5 13/16 | 6 5/16 | 1 1/4 | 3 13/16 | 2 3/4 | 3 5/8 | 2 |
| 3 1/2 | 4 3/4 | 2 1/2 | 3 15/16 | 3 | 4 1/8 | 13/16 | 3 3/8 | 5 9/16 | 2 5/8 | 6 1/4 | 6 11/16 | 1 5/16 | 4 1/16 | 3 | 3 7/8 | 2 1/8 |
| 3 3/4 | 5 | 2 11/16 | 4 1/4 | 3 1/8 | 4 3/8 | 7/8 | 3 5/8 | 6 | 2 13/16 | 6 3/4 | 7 1/4 | 1 7/16 | 4 3/8 | 3 1/8 | 4 1/4 | 2 3/8 |
| 4 | 5 3/8 | 2 13/16 | 4 1/2 | 3 3/8 | 4 3/4 | 15/16 | 3 7/8 | 6 3/8 | 3 | 7 1/8 | 7 11/16 | 1 1/2 | 4 11/16 | 3 3/8 | 4 1/2 | 2 1/2 |
| 4 1/4 | 5 3/4 | 3 | 4 3/4 | 3 5/8 | 5 | 1 | 4 | 6 3/4 | 3 3/16 | 7 5/8 | 8 3/16 | 1 5/8 | 4 15/16 | 3 5/8 | 4 3/4 | 2 5/8 |
| 4 1/2 | 6 | 3 3/16 | 5 1/16 | 3 3/4 | 5 1/4 | 1 | 4 1/4 | 7 1/16 | 3 3/8 | 8 1/16 | 8 5/8 | 1 11/16 | 5 1/4 | 3 3/4 | 5 | 2 7/8 |
| 4 3/4 | 6 3/8 | 3 3/8 | 5 3/8 | 4 | 5 1/2 | 1 1/16 | 4 1/2 | 7 1/2 | 3 9/16 | 8 1/2 | 9 1/16 | 1 3/4 | 5 9/16 | 4 | 5 1/4 | 3 |
| 5 | 6 3/4 | 3 9/16 | 5 5/8 | 4 1/8 | 5 7/8 | 1 1/8 | 4 3/4 | 7 7/8 | 3 3/4 | 8 15/16 | 9 9/16 | 1 7/8 | 5 13/16 | 4 1/8 | 5 5/8 | 3 1/8 |
| 5 1/4 | 7 | 3 3/4 | 5 7/8 | 4 3/8 | 6 1/8 | 1 3/16 | 5 | 8 1/4 | 3 15/16 | 9 3/8 | 10 1/8 | 2 | 6 1/8 | 4 3/8 | 5 7/8 | 3 1/4 |
| 5 1/2 | 7 3/8 | 3 15/16 | 6 3/16 | 4 5/8 | 6 3/8 | 1 1/4 | 5 1/4 | 8 11/16 | 4 1/8 | 9 7/8 | 10 9/16 | 2 1/16 | 6 7/16 | 4 5/8 | 6 1/8 | 3 1/2 |
| 5 3/4 | 7 3/4 | 4 1/16 | 6 1/2 | 4 3/4 | 6 3/4 | 1 5/16 | 5 1/2 | 9 1/8 | 4 5/16 | 19 1/4 | 11 | 2 1/8 | 6 3/4 | 4 3/4 | 6 1/2 | 3 5/8 |
| 6 | 8 | 4 1/4 | 6 3/4 | 5 | 7 | 1 3/8 | 5 3/4 | 9 1/2 | 4 1/2 | 10 3/4 | 11 1/2 | 2 1/4 | 7 | 5 | 6 3/4 | 3 3/4 |
| 6 1/4 | 8 3/8 | 4 7/16 | 7 | 5 1/4 | 7 1/4 | 1 7/16 | 6 | 9 7/8 | 4 11/16 | 11 1/4 | 12 | 2 3/8 | 7 1/4 | 5 1/4 | 7 | 3 7/8 |
| 6 1/2 | 8 3/4 | 4 5/8 | 7 5/16 | 5 1/2 | 7 5/8 | 1 1/2 | 6 1/4 | 10 5/16 | 4 7/8 | 11 5/8 | 12 7/16 | 2 7/16 | 7 9/16 | 5 1/2 | 7 3/8 | 4 |

Connecting Rod Stub End for Crank Pin. Forked Design with Back Block, Adjusting Key and Liner—*Continued*

| A | B | b | C | D | d | E | e | F | f | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6¾ | 9 | 4 13/16 | 7⅝ | 5¾ | 7⅞ | 1 9/16 | 6½ | 10¾ | 5 1/16 | 12 | 12 15/16 | 2 9/16 | 7 13/16 | 5¾ | 7½ | 4¼ |
| 7 | 9⅜ | 5 | 7⅞ | 6 | 8⅛ | 1⅝ | 6¾ | 11⅛ | 5¼ | 12½ | 13 7/16 | 2 11/16 | 8 1/16 | 6 | 7¾ | 4⅜ |
| 7¼ | 9¾ | 5⅛ | 8⅛ | 6⅛ | 8½ | 1 11/16 | 7 | 11½ | 5 7/16 | 13 | 13⅞ | 2¾ | 8⅜ | 6⅛ | 8⅛ | 4⅝ |
| 7½ | 10 | 5 5/16 | 8½ | 6⅜ | 8¾ | 1¾ | 7¼ | 12 | 5⅝ | 13½ | 14⅜ | 2⅞ | 8⅝ | 6⅜ | 8⅜ | 4¾ |
| 7¾ | 10⅜ | 5½ | 8¾ | 6⅝ | 9 | 1¾ | 7⅜ | 12¼ | 5 13/16 | 13⅞ | 14 15/16 | 3 | 8 15/16 | 6⅝ | 8⅝ | 4⅞ |
| 8 | 10¾ | 5 11/16 | 9 | 6⅞ | 9⅜ | 1 13/16 | 7⅝ | 12⅝ | 6 | 14⅜ | 15½ | 3⅛ | 9¼ | 6⅞ | 9 | 5 |

| A | m | N | O | P | Q | R | S | s | T | t | U | V | v | W | X | Y | Z |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | ½ | 7¾ | 1¼ | ½ | 4⅝ | 5 | 2 | ¼ | ¼ | ¼ | 4 | ⅞ | ⅝ | 3 | 2 | 1½ | ⅜ |
| 3¼ | ½ | 8⅜ | 1⅜ | ½ | 4 11/16 | 5⅜ | 2 3/16 | ¼ | ¼ | ¼ | 4¼ | 15/16 | 11/16 | 3¼ | 2 3/16 | 1⅝ | ⅜ |
| 3½ | ½ | 9 | 1⅜ | ⅝ | 5 3/16 | 6 | 2⅜ | ¼ | ¼ | 5/16 | 4⅝ | 1 | ¾ | 3½ | 2 5/16 | 1¾ | 7/16 |
| 3¾ | ½ | 9¾ | 1½ | ⅝ | 5½ | 6¼ | 2½ | 5/16 | 5/16 | 5/16 | 5 | 1 1/16 | 13/16 | 3¾ | 2½ | 1⅞ | 7/16 |
| 4 | ⅝ | 10⅜ | 1⅝ | ¾ | 6 | 6⅞ | 2 11/16 | 5/16 | ⅜ | 5/16 | 5¼ | 1⅛ | 13/16 | 4 | 2 11/16 | 2 | 7/16 |
| 4¼ | ⅝ | 11 | 1⅝ | ¾ | 6¼ | 7¼ | 2⅞ | 5/16 | 5/16 | ⅜ | 5⅝ | 1¼ | ⅞ | 4¼ | 2 13/16 | 2⅛ | ½ |
| 4½ | ⅝ | 11⅝ | 1¾ | ⅞ | 6 13/16 | 7¾ | 3 | 5/16 | ⅜ | ⅜ | 6 | 1 5/16 | 15/16 | 4½ | 3 | 2¼ | ½ |
| 4¾ | ⅝ | 12¼ | 1¾ | ⅞ | 7⅛ | 8⅛ | 3 3/16 | ⅜ | ⅜ | ⅜ | 6¼ | 1⅜ | 1 | 4¾ | 3⅛ | 2⅜ | ½ |
| 5 | ⅝ | 12⅞ | 1⅞ | 1 | 7⅝ | 8¾ | 3⅜ | ⅜ | 7/16 | 7/16 | 6⅝ | 1 7/16 | 1 1/16 | 5 | 3 5/16 | 2½ | ½ |
| 5¼ | ⅝ | 13½ | 2 | 1 | 7⅞ | 9 | 3½ | ⅜ | 7/16 | 7/16 | 7 | 1½ | 1⅛ | 5¼ | 3½ | 2⅝ | 9/16 |
| 5½ | ¾ | 14¼ | 2 | 1⅛ | 8 7/16 | 9⅝ | 3 11/16 | 7/16 | 7/6 | 7/16 | 7¼ | 1⅝ | 1⅛ | 5½ | 3 11/16 | 2¾ | 9/16 |
| 5¾ | ¾ | 14⅞ | 2⅛ | 1⅛ | 8¾ | 10 | 3⅞ | 7/16 | ½ | ½ | 7⅝ | 1 11/16 | 1 3/16 | 5¾ | 3 13/16 | 2⅞ | 9/16 |
| 6 | ¾ | 15½ | 2¼ | 1¼ | 9¼ | 10½ | 4 | ½ | ½ | ½ | 8 | 1¾ | 1¼ | 6 | 4 | 3 | ⅝ |
| 6¼ | ¾ | 16⅛ | 2⅜ | 1¼ | 9½ | 10⅞ | 4 3/16 | ½ | ½ | ½ | 8¼ | 1 13/16 | 1 5/16 | 6¼ | 4⅛ | 3⅛ | ⅝ |
| 6½ | ¾ | 16⅞ | 2½ | 1¼ | 9 13/16 | 11¼ | 4⅜ | ½ | ½ | 9/16 | 8⅝ | 1⅞ | 1⅜ | 6½ | 4¼ | 3⅜ | ⅝ |
| 6¾ | ¾ | 17½ | 2⅝ | 1¼ | 10⅛ | 11½ | 4½ | 9/16 | ½ | 9/16 | 9 | 1 15/16 | 1 7/16 | 6¾ | 4⅜ | 3 9/16 | 11/16 |
| 7 | ⅞ | 18⅛ | 2⅝ | 1¼ | 10⅜ | 11⅞ | 4 11/16 | 9/16 | ½ | 9/16 | 9¼ | 2 | 1 7/16 | 7 | 4½ | 3¾ | 11/16 |
| 7¼ | ⅞ | 18⅞ | 2¾ | 1¼ | 10⅝ | 12¼ | 4⅞ | ⅝ | 9/16 | ⅝ | 9⅝ | 2 1/16 | 1½ | 7¼ | 4⅝ | 3 15/16 | 11/16 |
| 7½ | ⅞ | 19½ | 2⅞ | 1¼ | 11 | 12½ | 5 | ⅝ | 9/16 | ⅝ | 10 | 2⅛ | 1 9/16 | 7½ | 4¾ | 4⅛ | 11/16 |
| 7¾ | ⅞ | 20⅛ | 3 | 1¼ | 11¼ | 12⅞ | 5 3/16 | ⅝ | 9/16 | ⅝ | 10¼ | 2 3/16 | 1⅝ | 7¾ | 4⅞ | 4 5/16 | ¾ |
| 8 | ⅞ | 20⅞ | 3¼ | 1¼ | 11½ | 13¼ | 5⅜ | 11/16 | 9/16 | 11/16 | 10½ | 2¼ | 1 11/16 | 8 | 5 | 4½ | ¾ |

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